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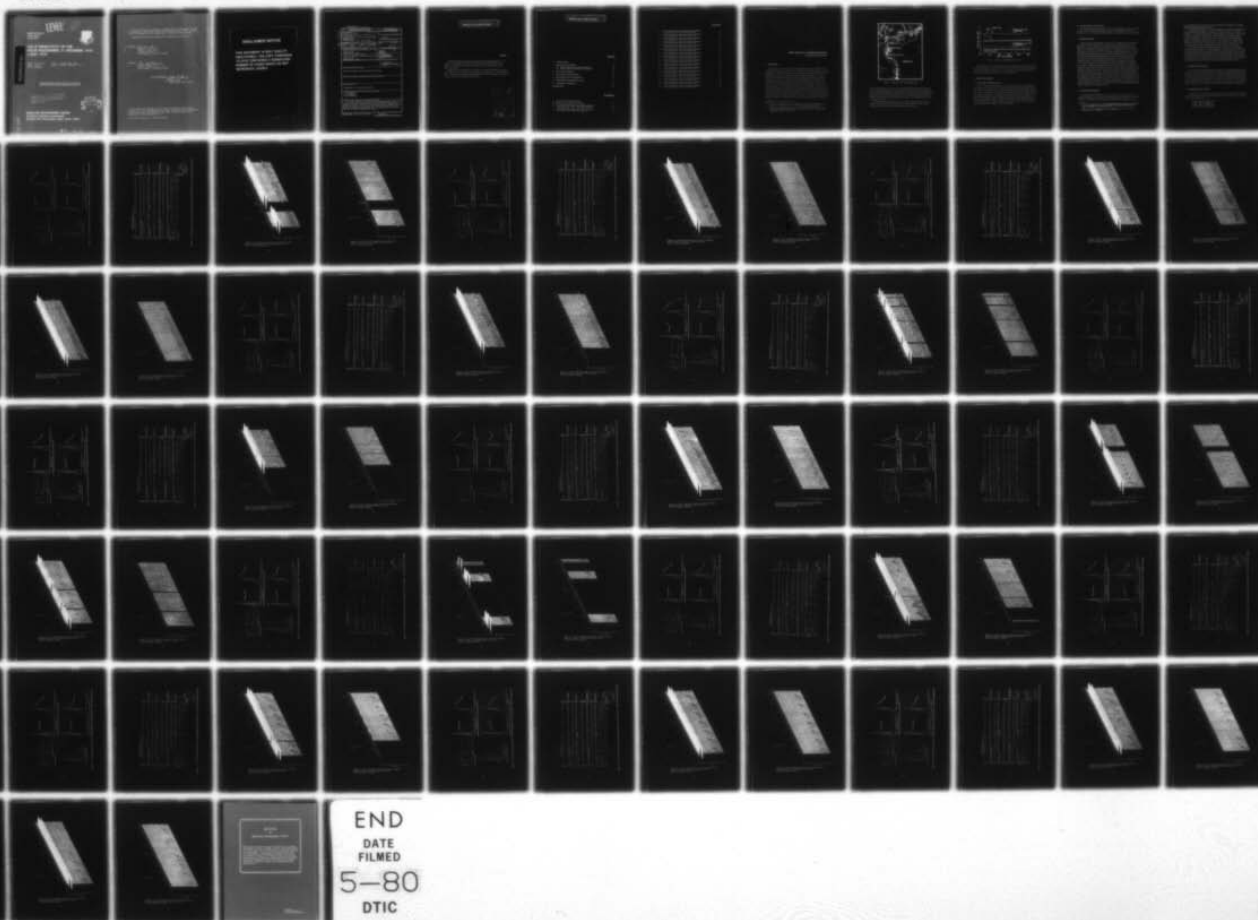
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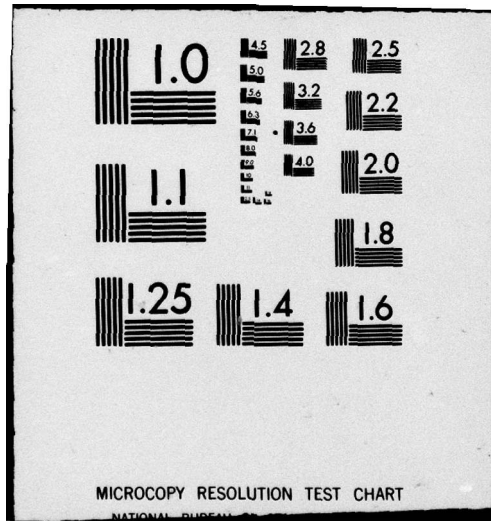
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In-House Report

October 1979



**VLF/LF REFLECTIVITY OF THE
POLAR IONOSPHERE, 31 DECEMBER 1978 -
5 MAY 1979**

Robert P. Pagliarulo
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John E. Rasmussen

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Preface

The authors thank in particular Mr. Duane Marshall of Megapulse, Inc., for help with the equipment that made the measurements possible, and Mr. Bjarne Ebbesen of the Danish Meteorological Institute for the outstanding operation at Qanaq, Greenland.

Appreciation is also extended to the Danish Commission for Scientific Research in Greenland for allowing these measurements to be conducted and to Jorgen Taagholt and V. Neble Jensen of the Danish Meteorological Institute's Ionospheric Laboratory for their continued cooperation in this program.

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VLF/LF Reflectivity of the Polar Ionosphere

31 December 1978—5 May 1979

1. INTRODUCTION

This report provides a summary of high latitude ionospheric reflectivity data, as observed by the USAF's high resolution VLF/LF ionosounder operating in northern Greenland.^{1,2} As shown in Figure 1, the transmitter is located at Thule Air Base, Greenland (76° 33'N. Lat., 68° 40'W. Long.), and the receiving site is 106 km north at the Danish Meteorological Institute's Ionospheric Observatory in Qanaq, Greenland (77° 24'N. Lat., 69° 20'W. Long., Geomagnetic Lat. 89° 06'N). The ionosounding transmissions consist of a series of extremely short (approximately 100 μ sec) VLF pulses, precisely controlled in time, and radiated from a 130 m vertical antenna. At the receiving site, orthogonal loop antennas are used to separate the two polarization components of the ionospherically reflected skywave signal. One antenna, oriented in the plane of propagation, is used to sense the groundwave and the transmitted or "parallel" polarization component of the skywave. The second loop, nulled on the groundwave, senses the converted or "perpendicular" polarization skywave component. The signal from each of the antennas is digitally averaged to

(Received for publication 9 October 1979)

1. Lewis, E. A., Rasmussen, J. E., and Kossey, P. A. (1973) Measurements of ionospheric reflectivity from 6 to 35 kHz, *J. Geophys. Res.* **78**:19.
2. Kossey, P. A., Rasmussen, J. E., and Lewis, E. A. (1974) VLF pulse ionosounder measurements of the reflection properties of the lower ionosphere, *Akademie Verlag, COSPAR*, July.

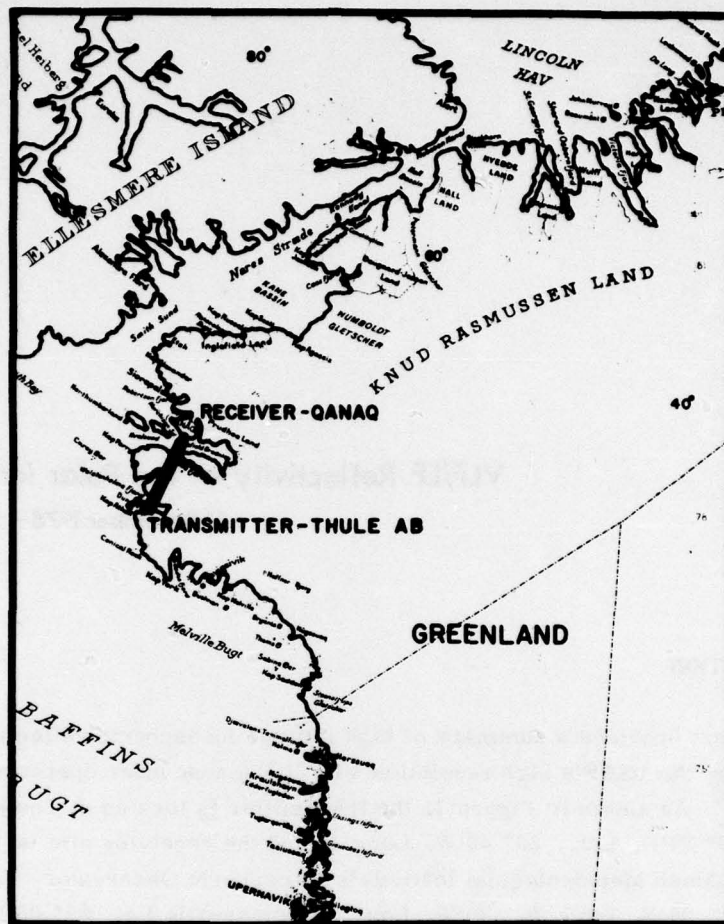


Figure 1. Geometry of the Propagation Path

improve the signal-to-noise ratio of the individual received waveforms before they are recorded on magnetic tape. An example of the observed waveforms is given in Figure 2, where the "parallel" waveform (Figure 2a) consists of a groundwave propagated pulse, a quiet interval containing low level, off path groundwave reflections, followed by the first-hop parallel skywave component. The perpendicular waveform is shown in Figure 2b.

Ionospheric reflection parameters are derived by computer processing of the ground and ionospherically reflected waveforms with allowance made for factors such as ground conductivity and antenna patterns (see Section 4).

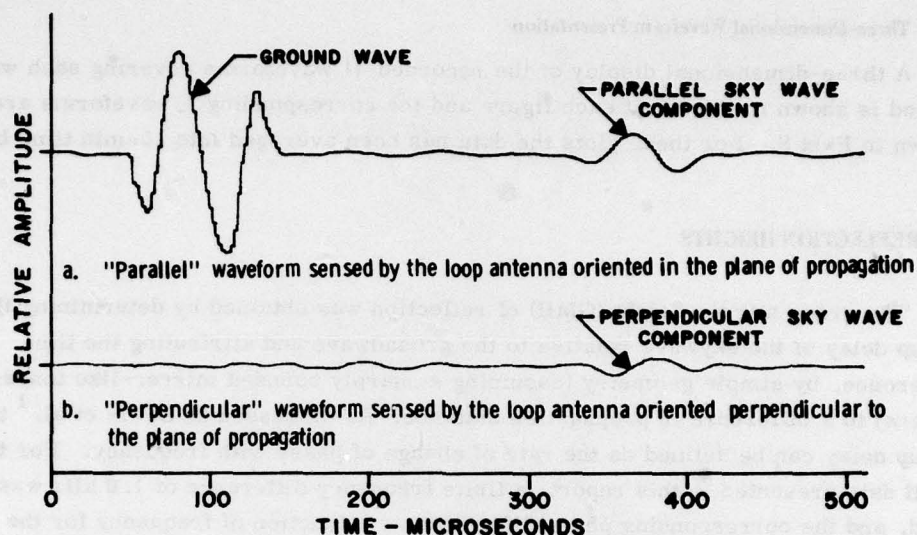


Figure 2. Example of the Observed Waveforms

Although the data are recorded about once per minute, for this report the waveforms are averaged into 2-hr time blocks with the exception of the three-dimensional waveform presentations (Section 2.2). The resulting information is presented in a weekly format (Figures 3 through 20 as described below).

2. OBSERVED WAVEFORMS

2.1 Weekly Example of Individual Waveforms

In part A of Figures 3 through 20, a set of averaged parallel and perpendicular waveforms is presented for the time block centered near local noon of the indicated day. Each of these waveforms is comprised of 256 digitally averaged points spaced $2 \mu\text{sec}$ apart. In part B of the figures, the groundwave Fourier amplitudes are shown as a function of frequency. Although the data presented in parts C through L of the figures are generally limited to frequencies in the first, or principal, lobe of the spectrum, information at higher frequencies can be used when sufficient signal-to-noise conditions exist. There is, however, a frequency range around each spectral null where insufficient signal exists for measurements.

2.2 Three-Dimensional Waveform Presentation

A three-dimensional display of the recorded \parallel waveforms covering each weekly period is shown in Part R of each figure and the corresponding \perp waveforms are shown in Part S. For these plots the data has been averaged into 15-min time blocks.

3. REFLECTION HEIGHTS

The group mirror height (GMH) of reflection was obtained by determining the group delay of the skywave relative to the groundwave and attributing the time difference, by simple geometry (assuming a sharply bounded mirror-like ionosphere) to a difference in propagation distance. As discussed in Lewis et al.,¹ the group delay can be defined as the rate of change of phase with frequency. For the GMH data presented in this report, a finite frequency difference of 1.0 kHz was used, and the corresponding phase difference as a function of frequency for the groundwave and both skywave signals was obtained by Fourier analysis of the respective pulses. The GMH calculations took into account ground conductivity (10^{-3} mho/m is assumed), and the corrections of Wait and Howe³ were applied. Group mirror heights, obtained from the parallel and perpendicular waveforms, are plotted as a function of frequency in parts C and D of Figures 3 through 20. The GMH's are also presented as a function of time-of-day for the average frequency of 16.5 kHz in figure parts E and I. The parallel GMH's in part E are shown along with an average reflection height for reference purposes. Each point of the reference height is a weekly average, by time block, for the 7-day period indicated. The corresponding perpendicular GMH's, part I of the figures, are also shown with the weekly average for comparison. Part G gives the average, by time block, for the daily parallel GMH data of part E, and part K gives the corresponding perpendicular GMH averages from the daily data of part I.

4. REFLECTION COEFFICIENTS

Assuming that the ionosphere acts as a "mirror" at the GMH, plane wave reflection coefficients⁴ were obtained by comparing the ratio of the skywave Fourier amplitude at a specific frequency to that of the groundwave, taking into account

3. Wait, J. R., and Howe, H. H. (1956) Amplitude and Phase Curves for Ground-Wave Propagation in the Band 200 Cycles per Second to 500 Kilocycles, Nat. Bur. Stand. U.S. Circ. No. 574.

4. Budden, K. G. (1961) Radio Waves in the Ionosphere, p. 85, Cambridge University Press, London.

wave spreading, earth curvature, ground conductivity, path lengths, and antenna patterns including ground image effects.

The reflection coefficient $||R||$ was obtained from analysis of the parallel sky-wave component and is plotted as a function of frequency in part C of Figures 3 through 20. The $||R||$ coefficient for 16 kHz is plotted as a function of time-of-day in part F along with the average of the indicated week for reference purposes. From the perpendicular skywave pulse, the coefficient $||R\perp||$ was obtained and appears as a function of frequency in part D. The 16 kHz $||R\perp||$ is shown along with its reference in part J. Parts H and L present the average, by time block, of the daily $||R||$ and $||R\perp||$ data presented in parts F and J, respectively.

For certain coefficient data points, plotted as asterisks (*), the reflection coefficient appears without a corresponding GMH. For these particular data, only the skywave-groundwave ratios could be obtained as the skywaves were too weak to provide reliable group delay information. The reflection coefficients were therefore estimated using a nominal GMH of 80 km in the calculations. These estimated coefficient values are included in the averages presented in parts H and L, but the assumed heights are not used in the GMH averages shown in parts G and K.

5. SUPPLEMENTARY INFORMATION

For purposes of comparison and interpretation, certain supplementary data are presented. Part M of the figures shows the magnitude of the horizontal component of the polar magnetic field as recorded on a three-axis fluxgate magnetometer and part N presents 30-MHz riometer data, an indicator of D-region particle precipitation. These supplementary data were recorded at 30-sec intervals by RADC/EEP at Thule AB; the curves represent the average of 10-min periods. The solar zenith angle is given in part O of Figures 3 through 20 for the indicated mid-week date.

6. IONOSPHERIC DISTURBANCE DATA

During the period covered by this report solar activity continued at a moderate level. The effects of energetic particle disturbances can be seen in the data beginning on the following dates:

2 Mar (DAY 61, Figures 11-12)
11 Mar (DAY 70, Figure 13)
28 Mar (DAY 87, Figure 15)
3 Apr (DAY 93, Figure 16)
24 Apr (DAY 114, Figure 19).

The strongest of these disturbances, that of 3 Apr (DAY 93), produced 2.5 dB absorption on the 30 MHz riometer. The other events were quite small, producing less than 1 dB absorption. The transient effects of Sudden Ionospheric Disturbances (SID) resulting from solar flares can be seen in the 3-D plots of the waveforms. The strongest of these occurred on 2 May (DAY 122, Figure 20) at about 1700 UT and was caused by an M9 X-ray flare.

During strong ionospheric disturbances, when enhanced ionization produces a lowering of the VLF/LF reflection heights, the skywave moves closer to the ground-wave as seen on the waveform plots. In particularly energetic events the skywave can merge with the low level off-path signal reflections (described in Section 1, Introduction). During these periods the constant off-path groundwave reflections are computer subtracted from the waveforms so as not to interfere with the sky-wave reflections. During the period covered by this report this subtraction technique was used in the parallel and perpendicular waveform data for the weekly periods beginning on the following days: DAY 56 (Figure 11), DAY 63 (Figure 12), DAY 70 (Figure 13), DAY 84 (Figure 15), and DAY 91 (Figure 16).

7. ADDITIONAL COMMENTS

This report is one of a series.⁵⁻¹⁷ Comments and suggestions for improving its usefulness should be addressed to the Propagation Branch (EEP), Electromagnetic Sciences Division, Deputy for Electronic Technology (RADC/EEP), Hanscom AFB, Massachusetts 01731.

(Because of the large number of references cited above, they will not be listed here. See Reference Page 13, for References 5 through 17.)

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17. Pagliarulo, R.P., Turtle, J.P., Rasmussen, J.E., Cooley, R.L., TSgt, and Klemetti, W.I. (1979) VLF/LF Reflectivity of the Polar Ionosphere, 3 September - 30 December 1978, RADC-TR-79-178, AD A074475.

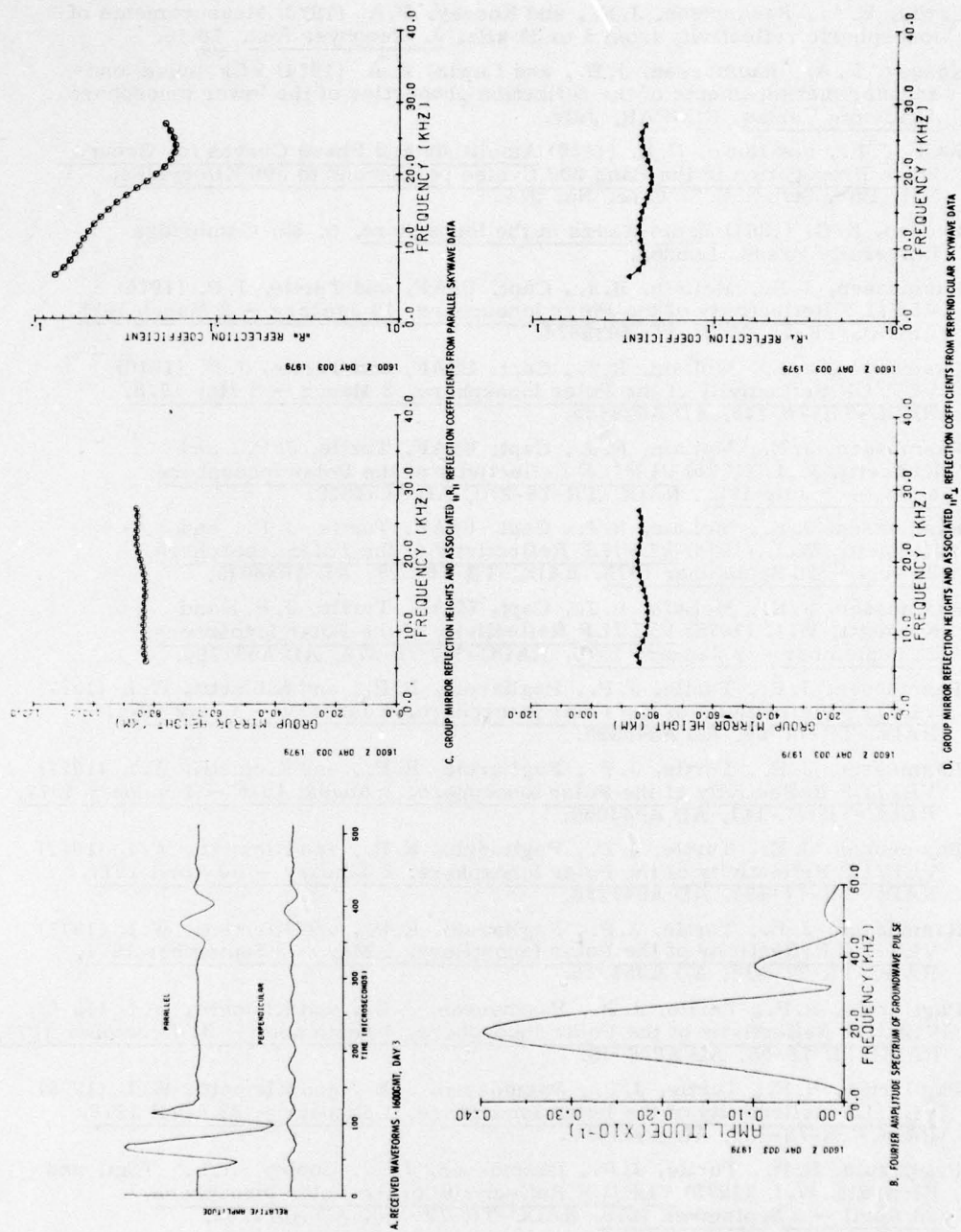


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 365 (31 Dec) 1978 - DAY 006 (6 Jan) 1979

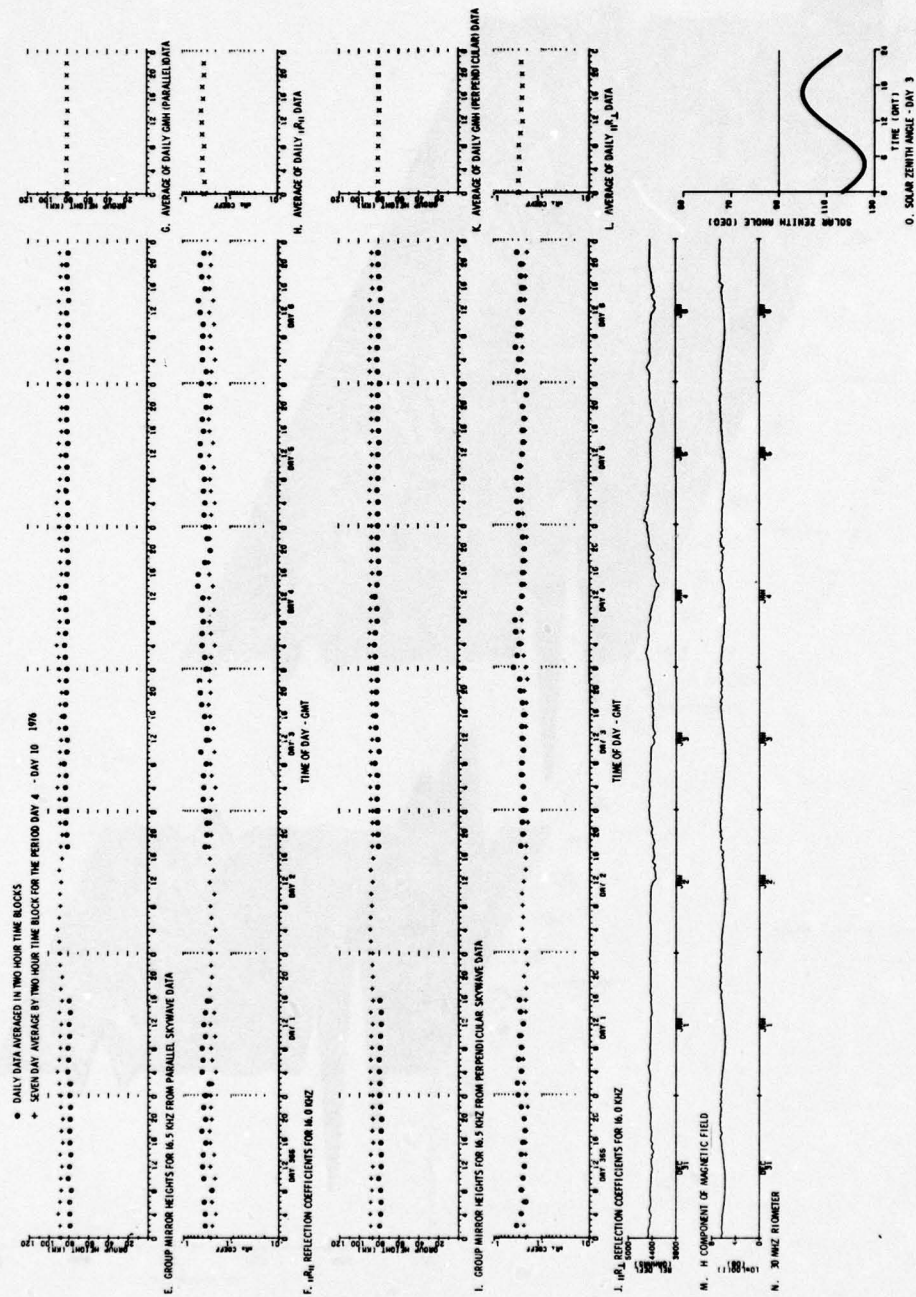


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 365 (31 Dec) 1978 — DAY 006 (6 Jan) 1979 (Cont)

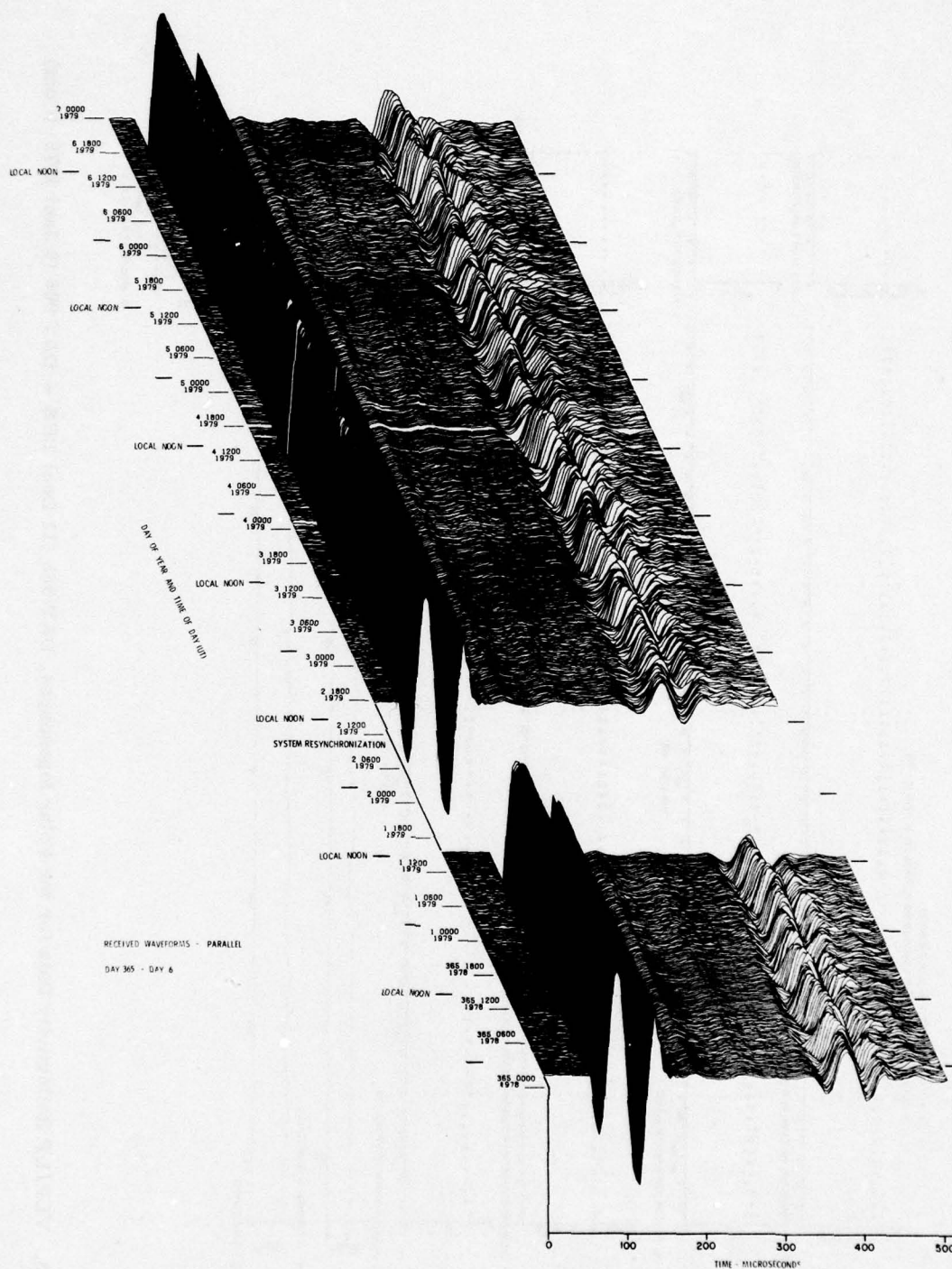


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 365 (31 Dec) 1978 - DAY 006 (6 Jan) 1979 (Cont)
Part R. II Waveform Display

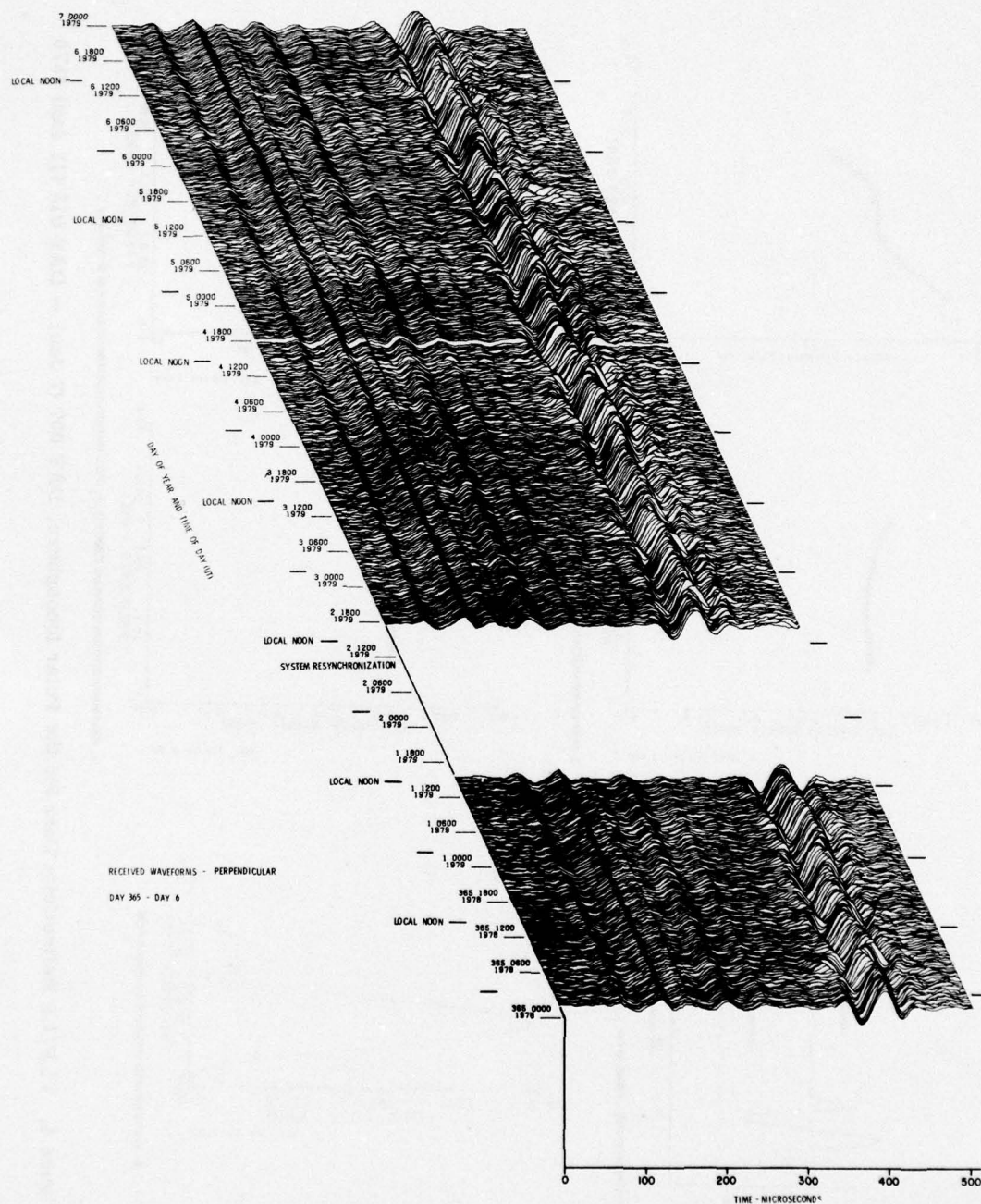


Figure 3. VLF/LF Reflectivity Data for the Polar Ionosphere,
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Part S. \perp Waveform Display

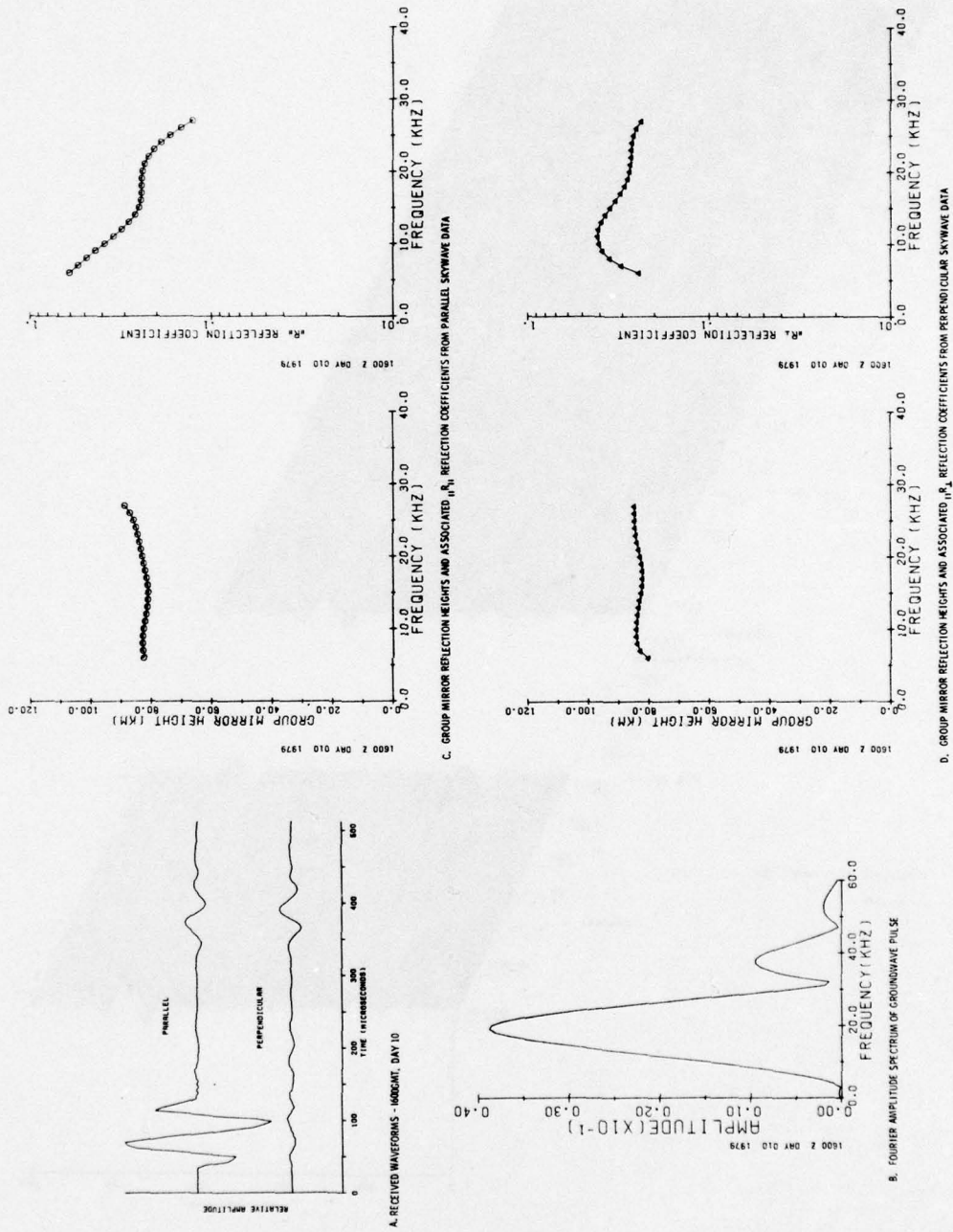


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 007 (7 Jan) - DAY 013 (13 Jan) 1979

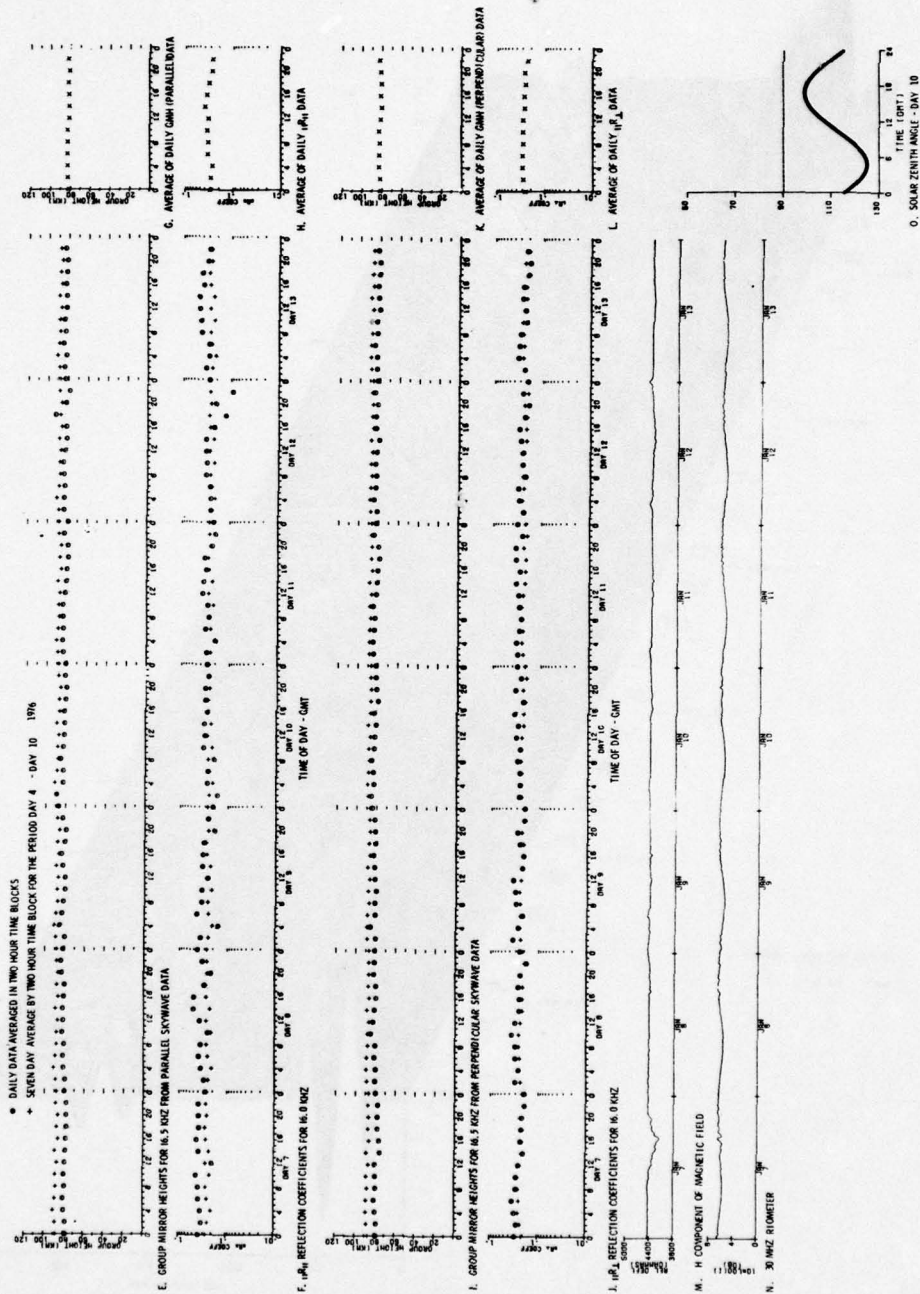


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 007 (7 Jan) - DAY 013 (13 Jan) 1979 (Cont)

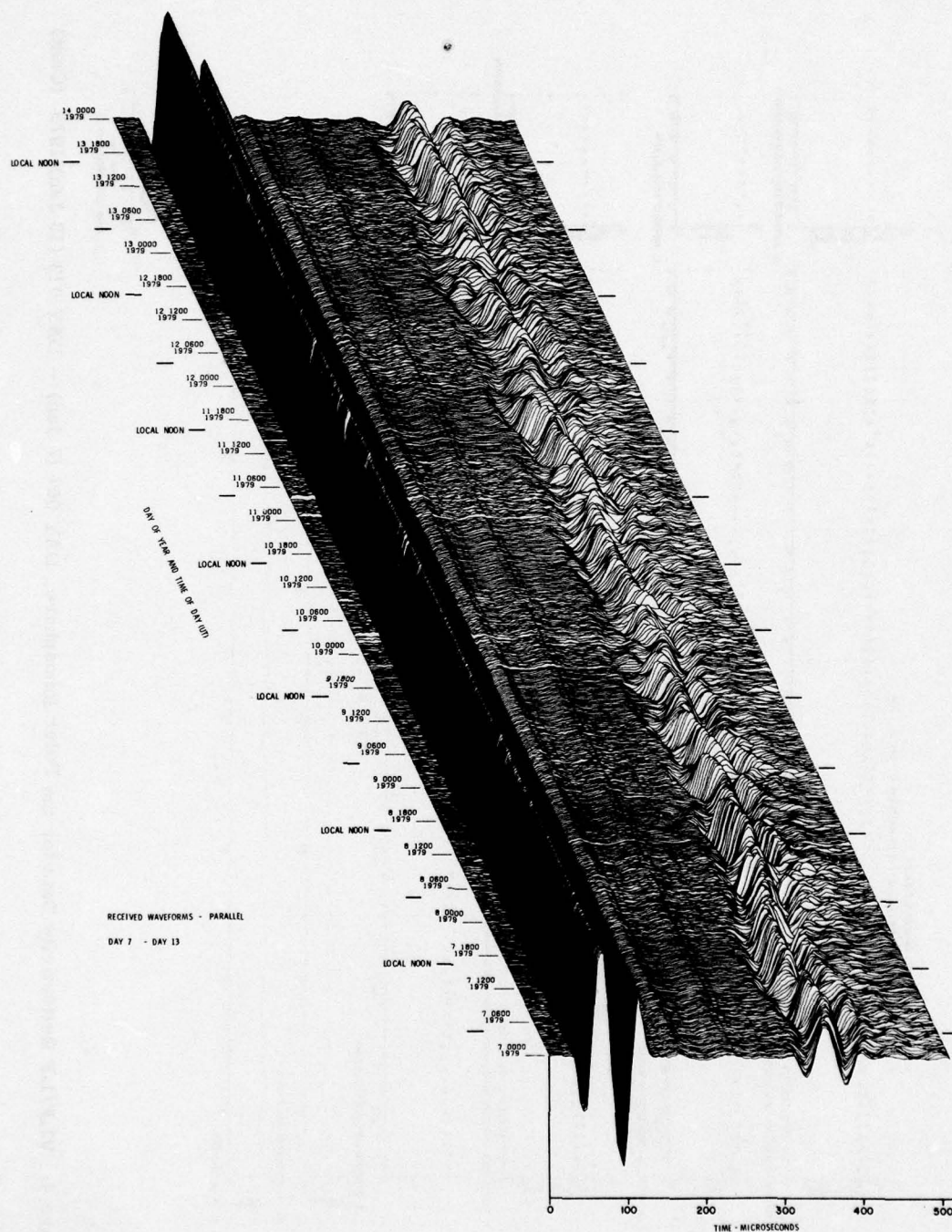


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 007 (7 Jan) - DAY 013 (13 Jan) 1979 (Cont)
Part R. II Waveform Display

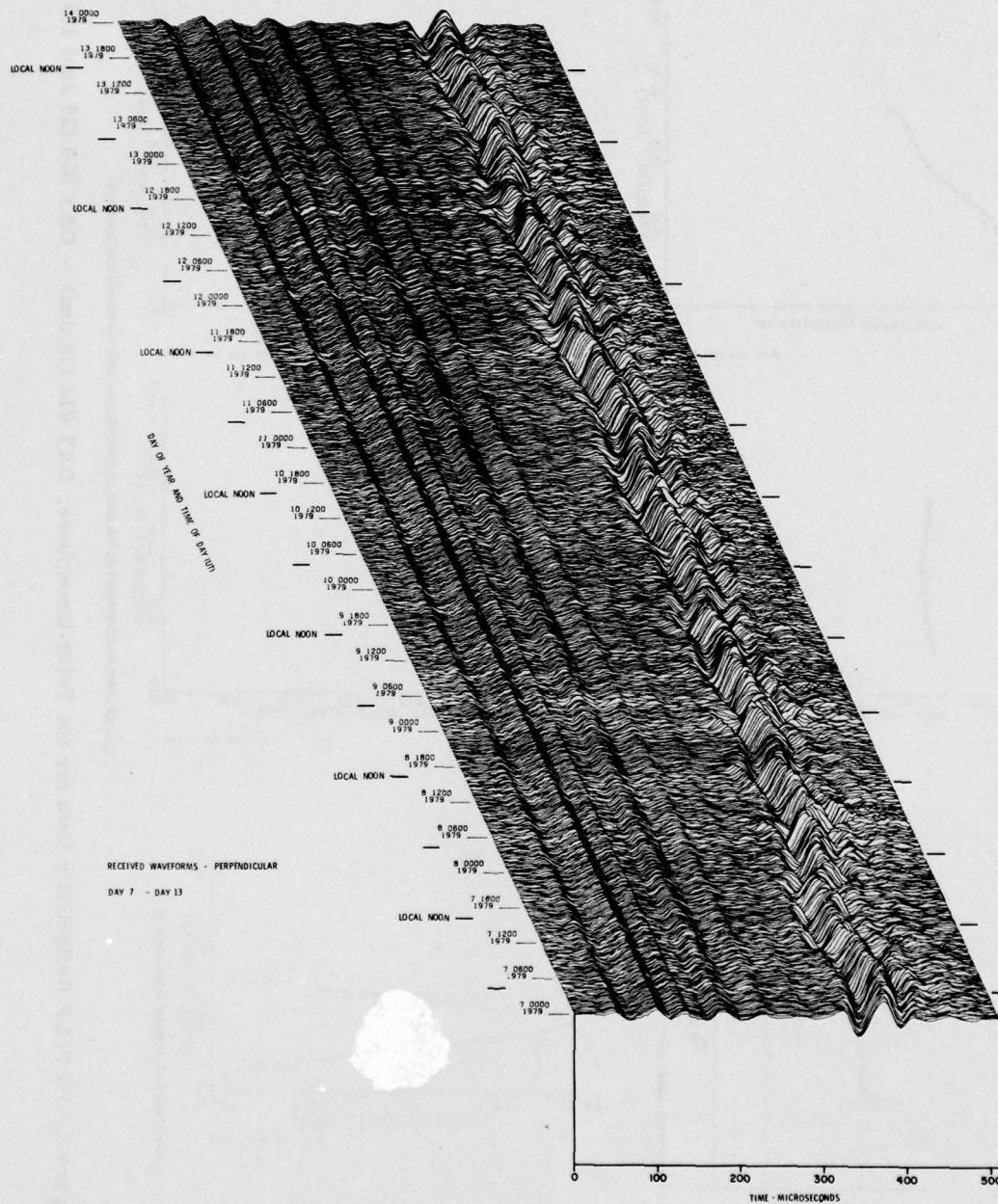


Figure 4. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 007 (7 Jan) - DAY 013 (13 Jan) 1979 (Cont)
Part S. \perp Waveform Display

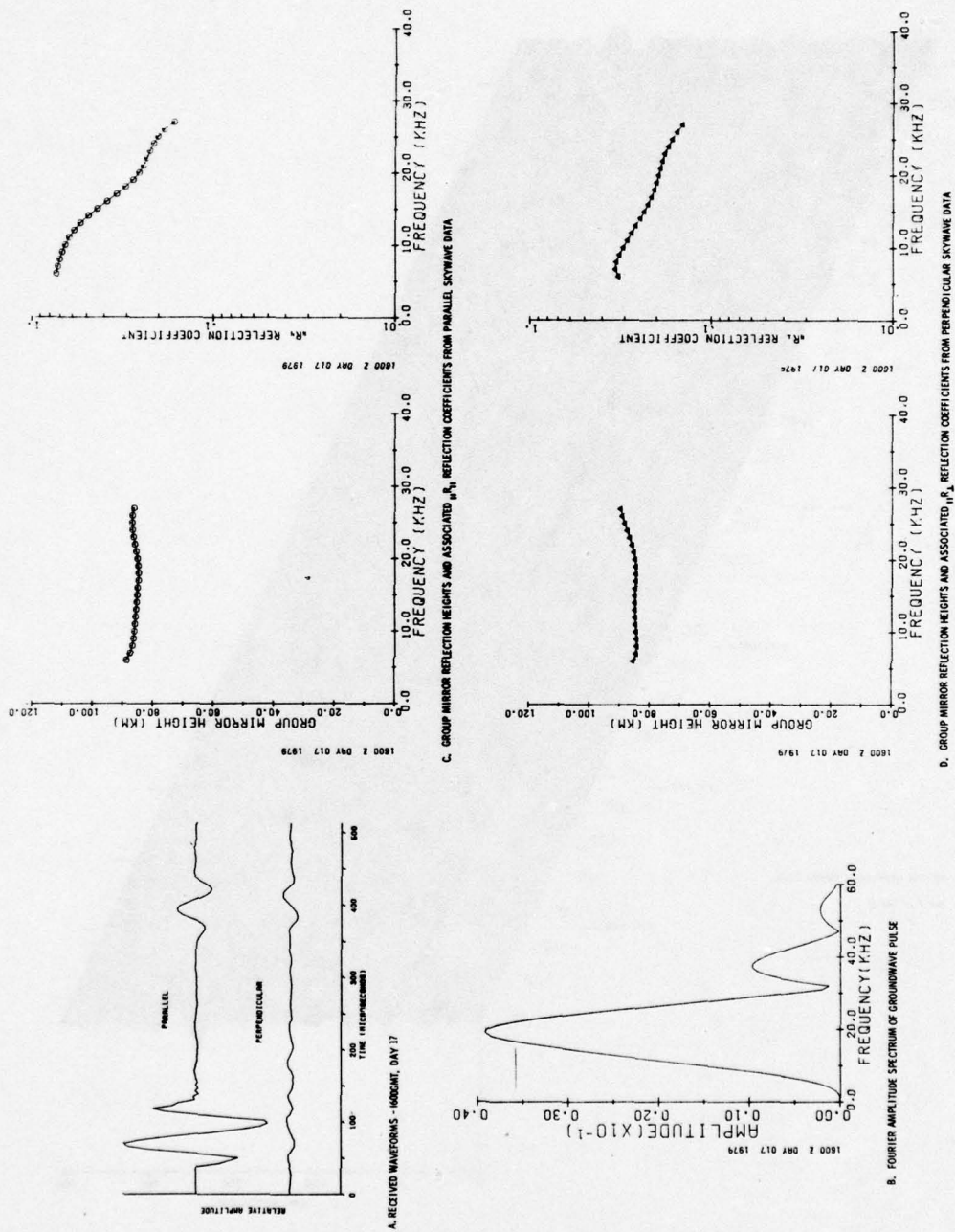


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 014 (14 Jan) - DAY 020 (20 Jan) 1979



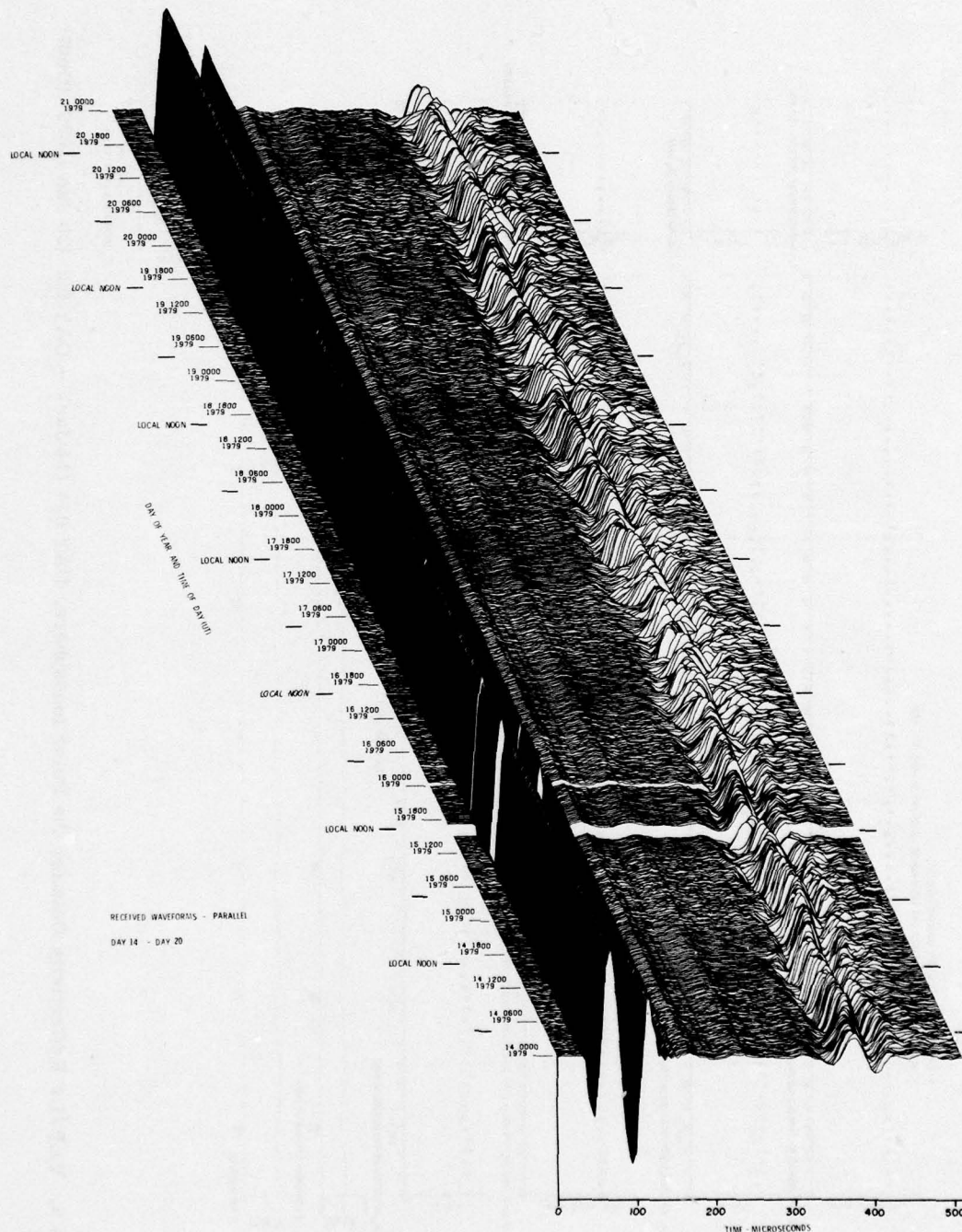


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 014 (14 Jan) - DAY 020 (20 Jan) 1979 (Cont)
Part R. II Waveform Display

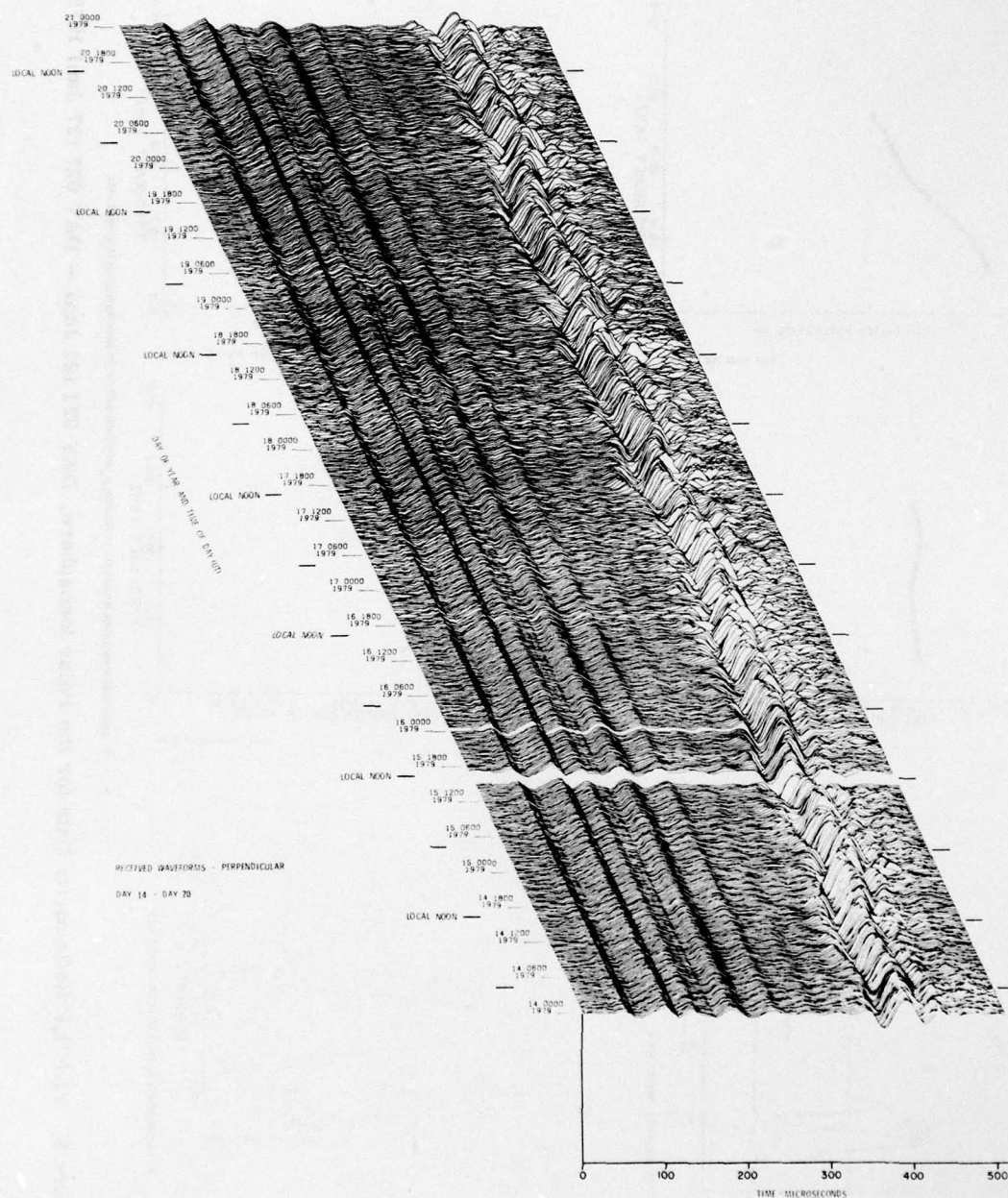


Figure 5. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 014 (14 Jan) - DAY 020 (20 Jan) 1979 (Cont)
Part S. 1 Waveform Display

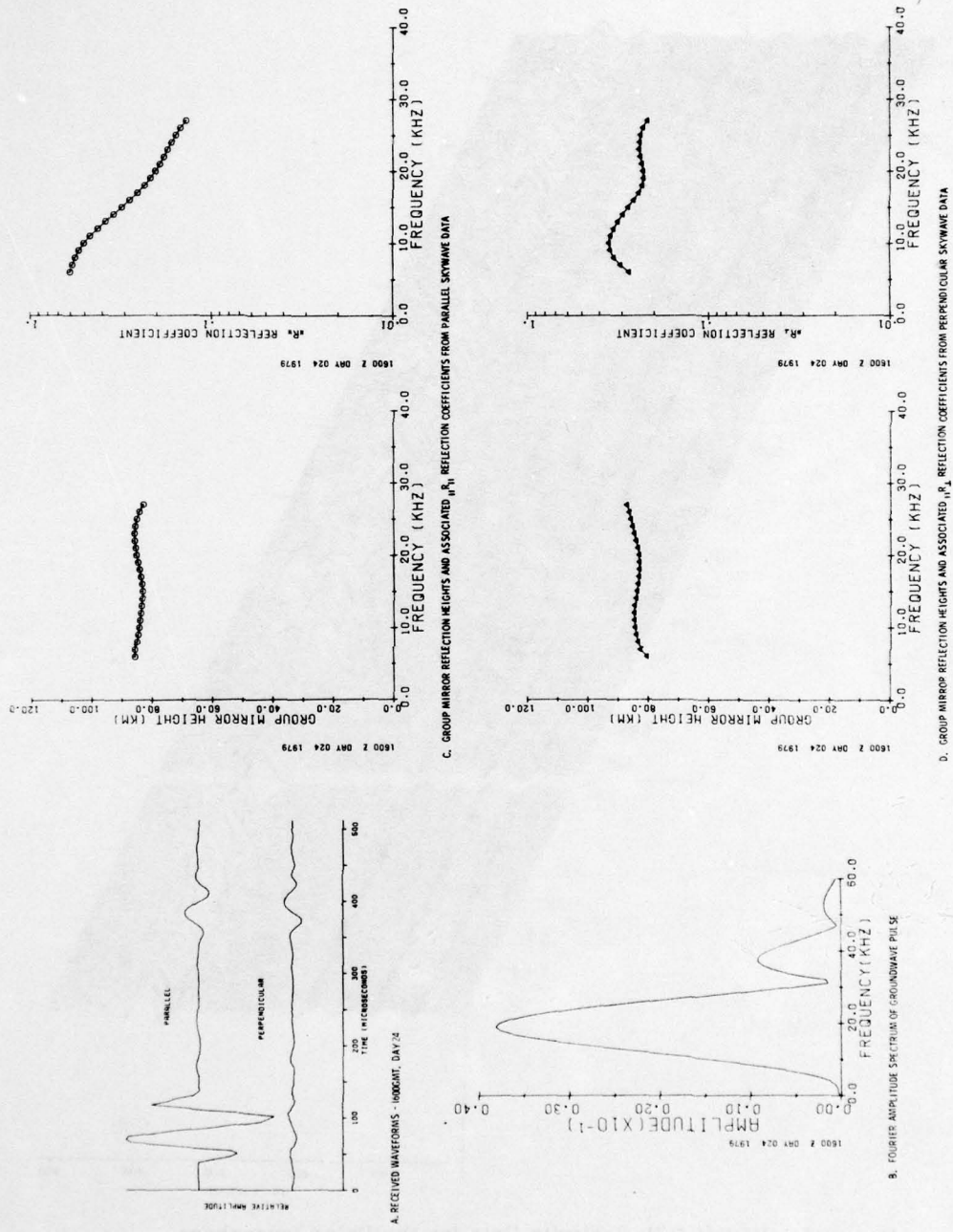


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 021 (21 Jan) - DAY 027 (27 Jan) 1979

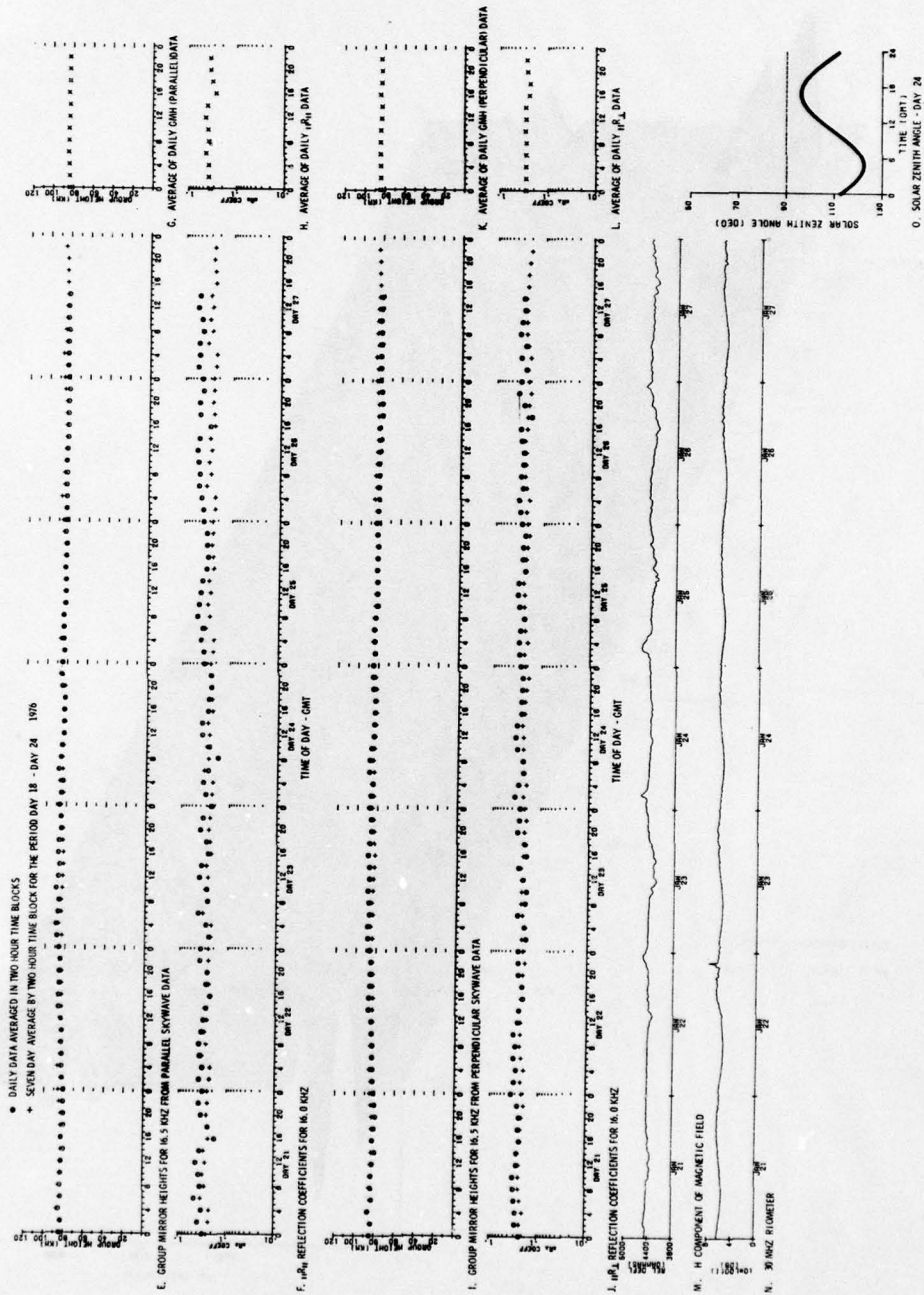


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 021 (21 Jan) - DAY 027 (27 Jan) 1979 (Cont)

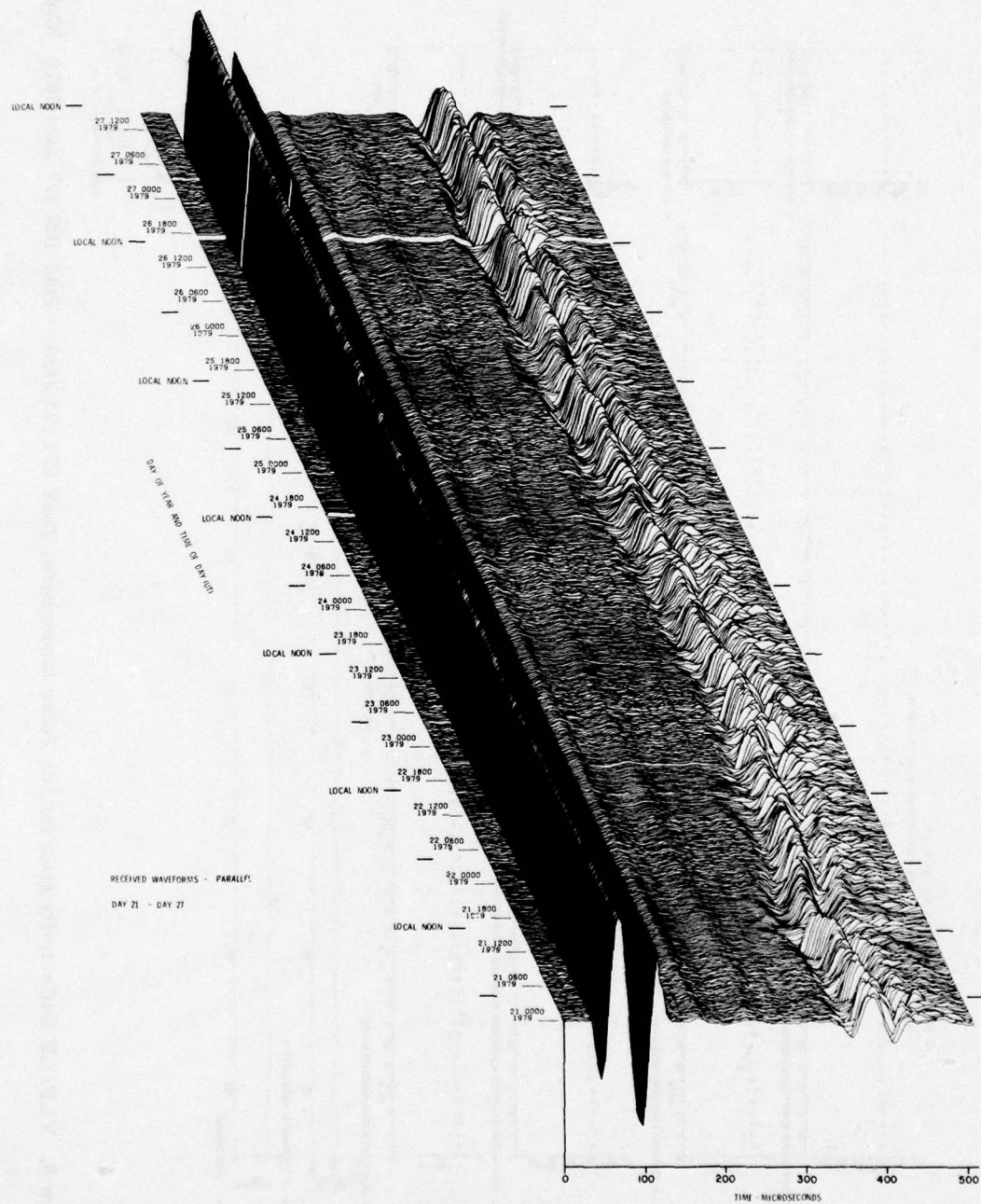


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 021 (21 Jan) - DAY 027 (27 Jan) 1979 (Cont)
Part R. II Waveform Display

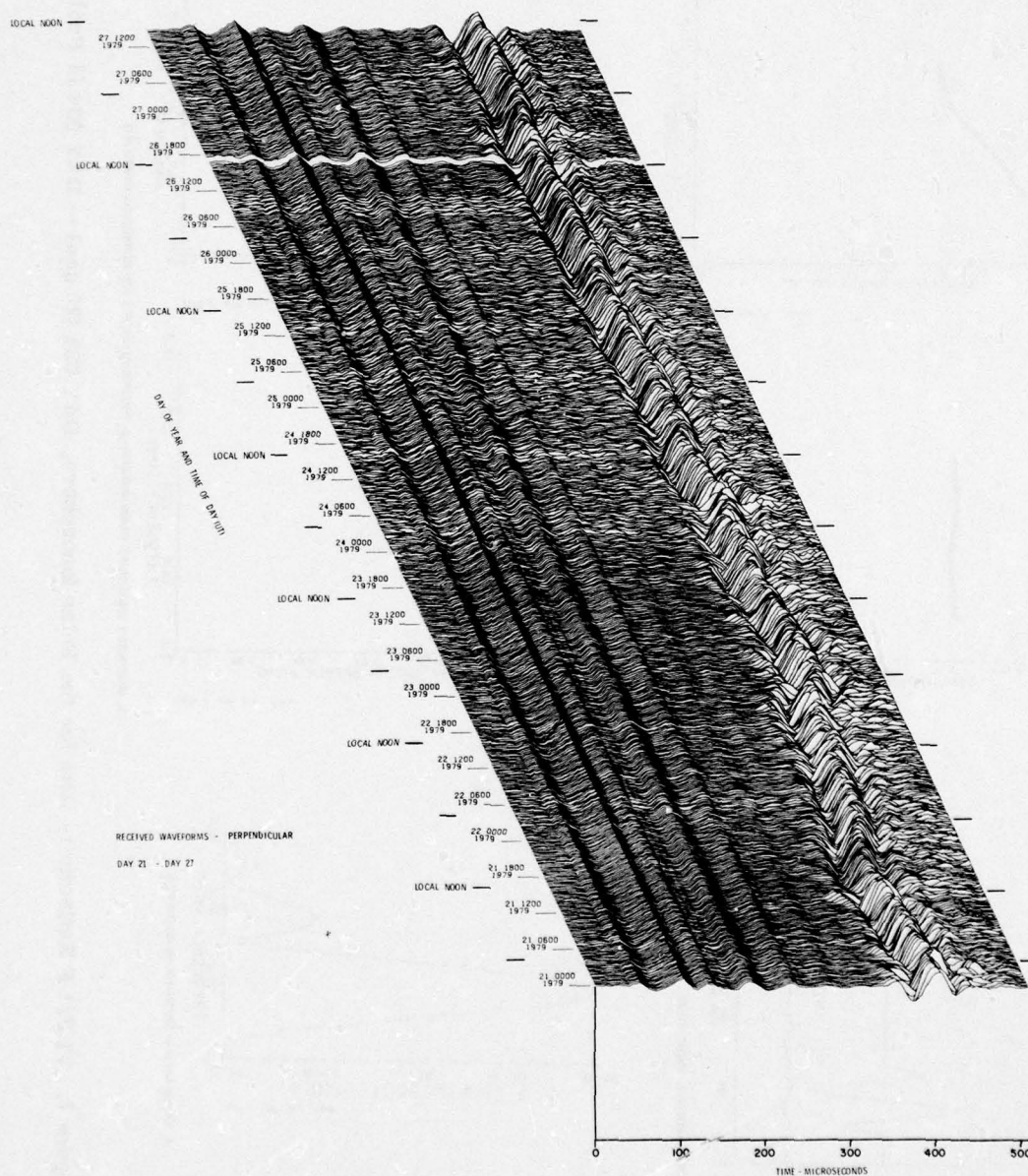


Figure 6. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 021 (21 Jan) - DAY 027 (27 Jan) 1979 (Cont)
Part S. \perp Waveform Display

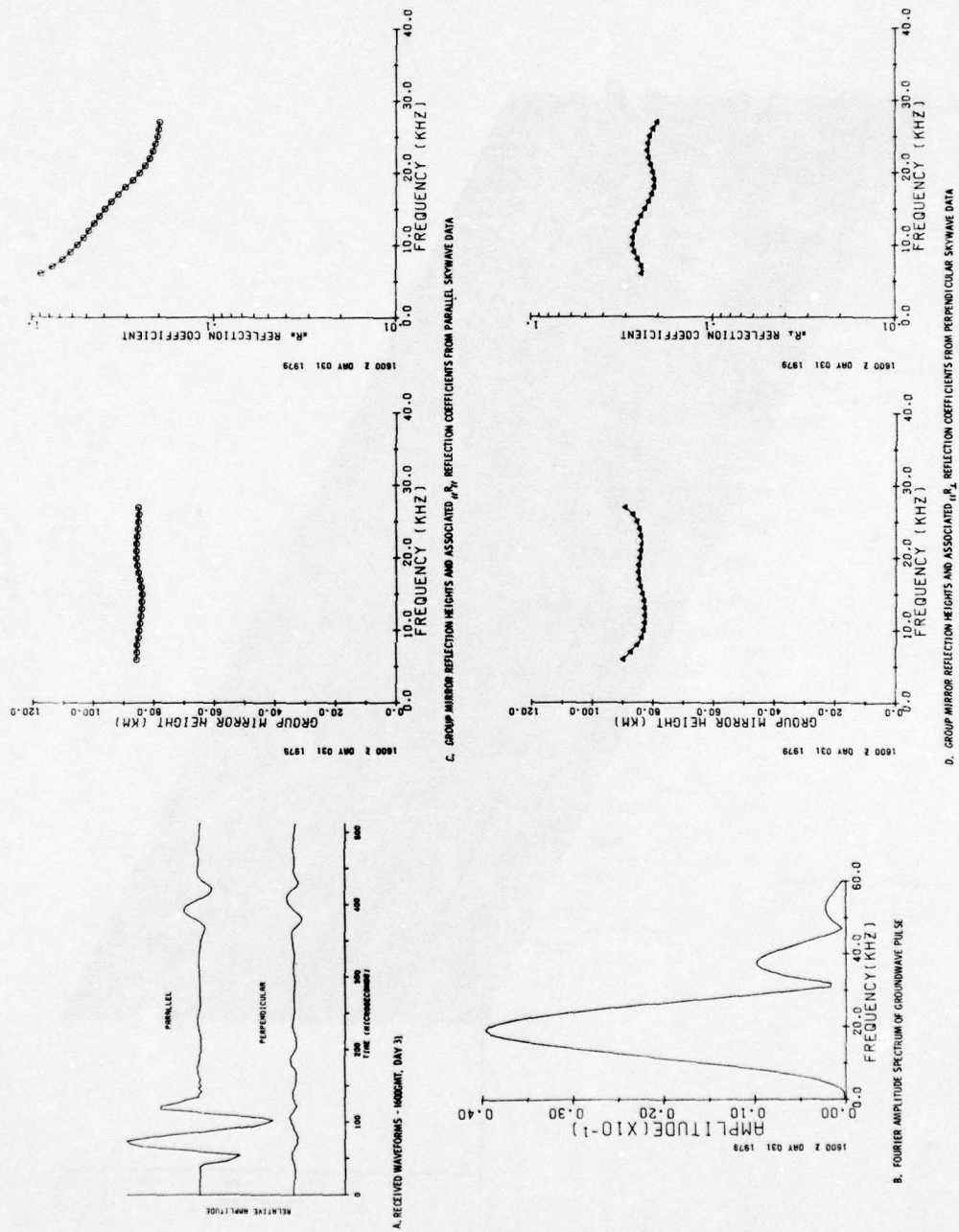


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 028 (28 Jan) - DAY 034 (3 Feb) 1979

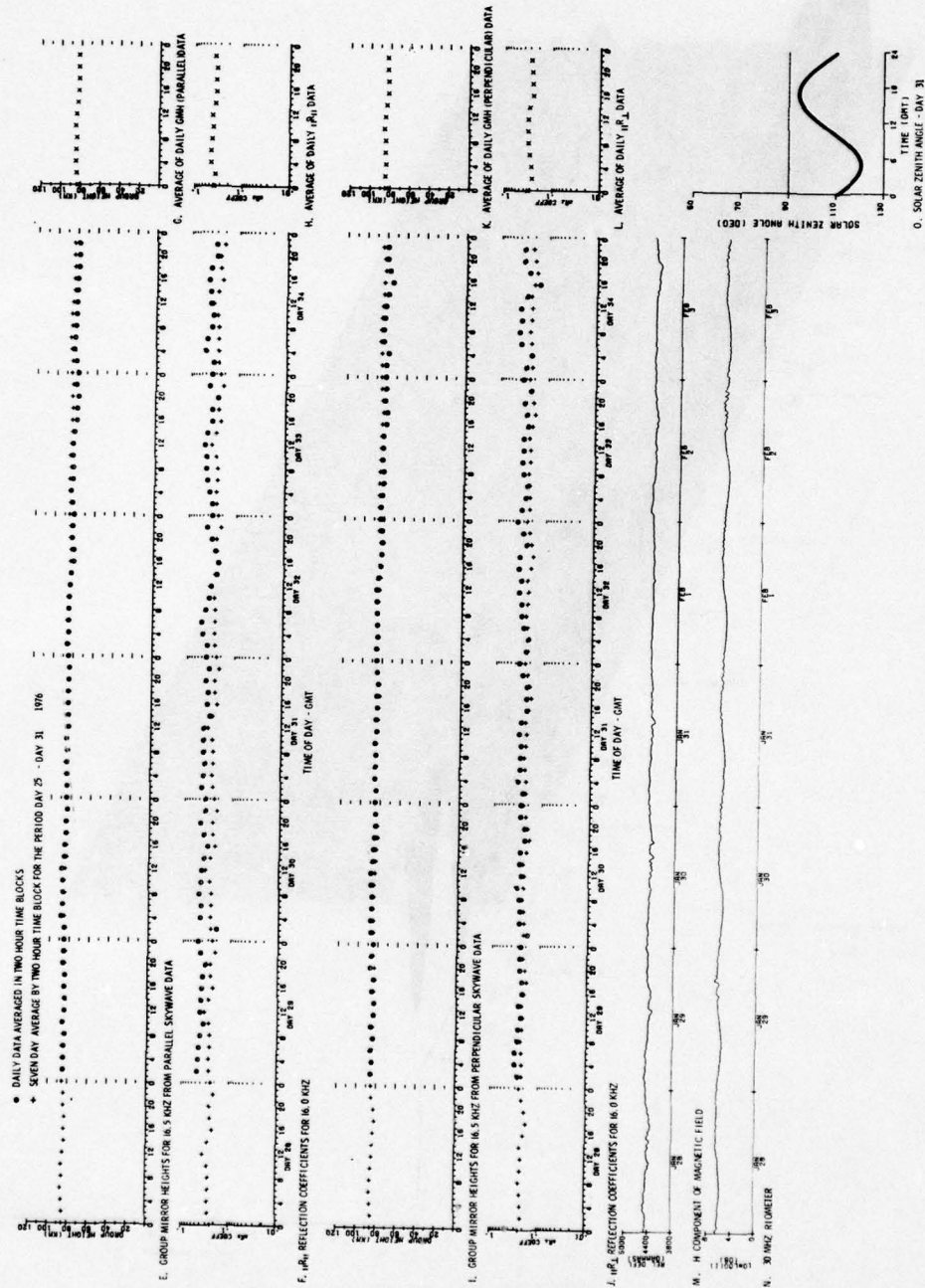


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 028 (28 Jan) - DAY 034 (3 Feb) 1979 (Cont)

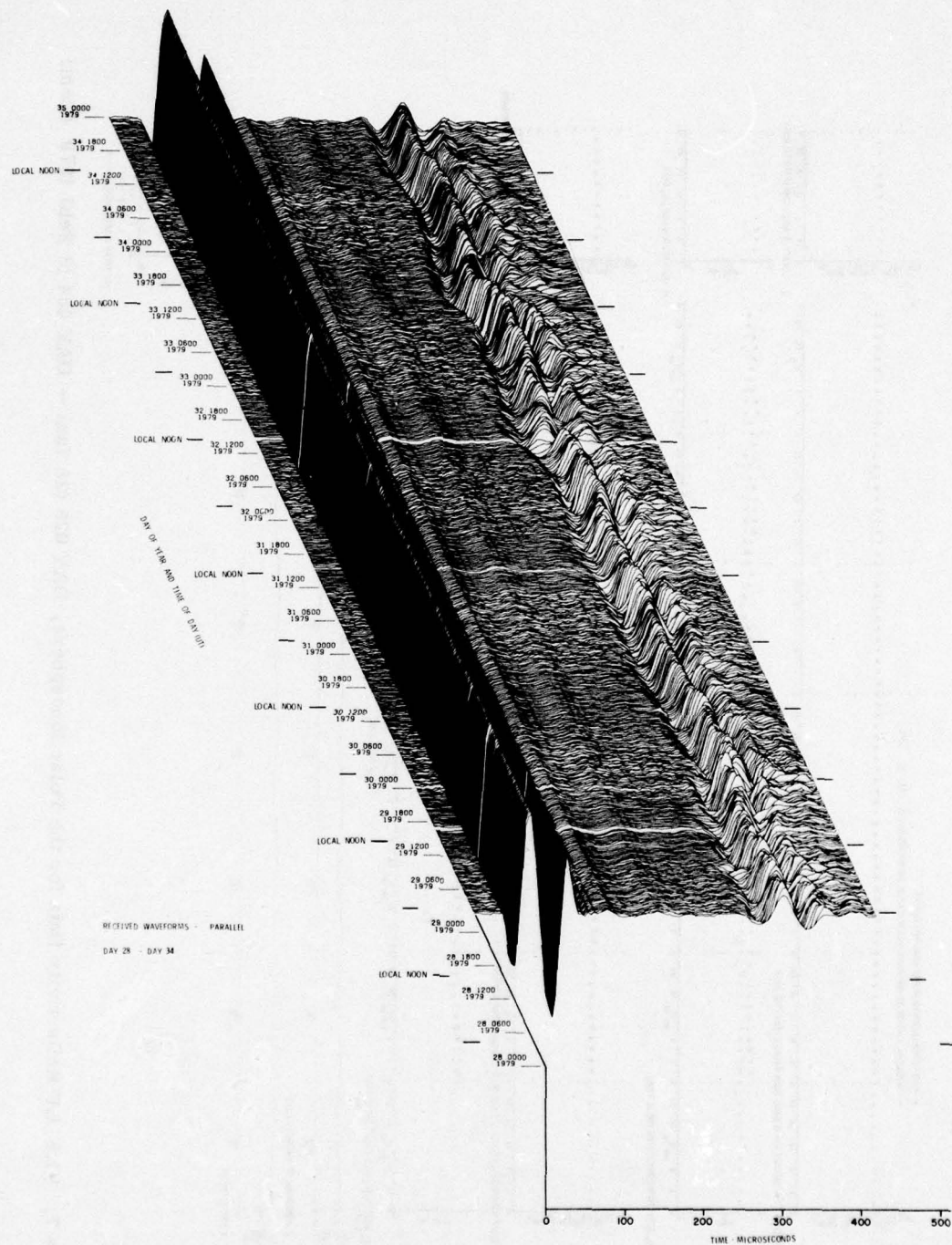


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 028 (28 Jan) - DAY 034 (3 Feb) 1979 (Cont)
Part R. II Waveform Display

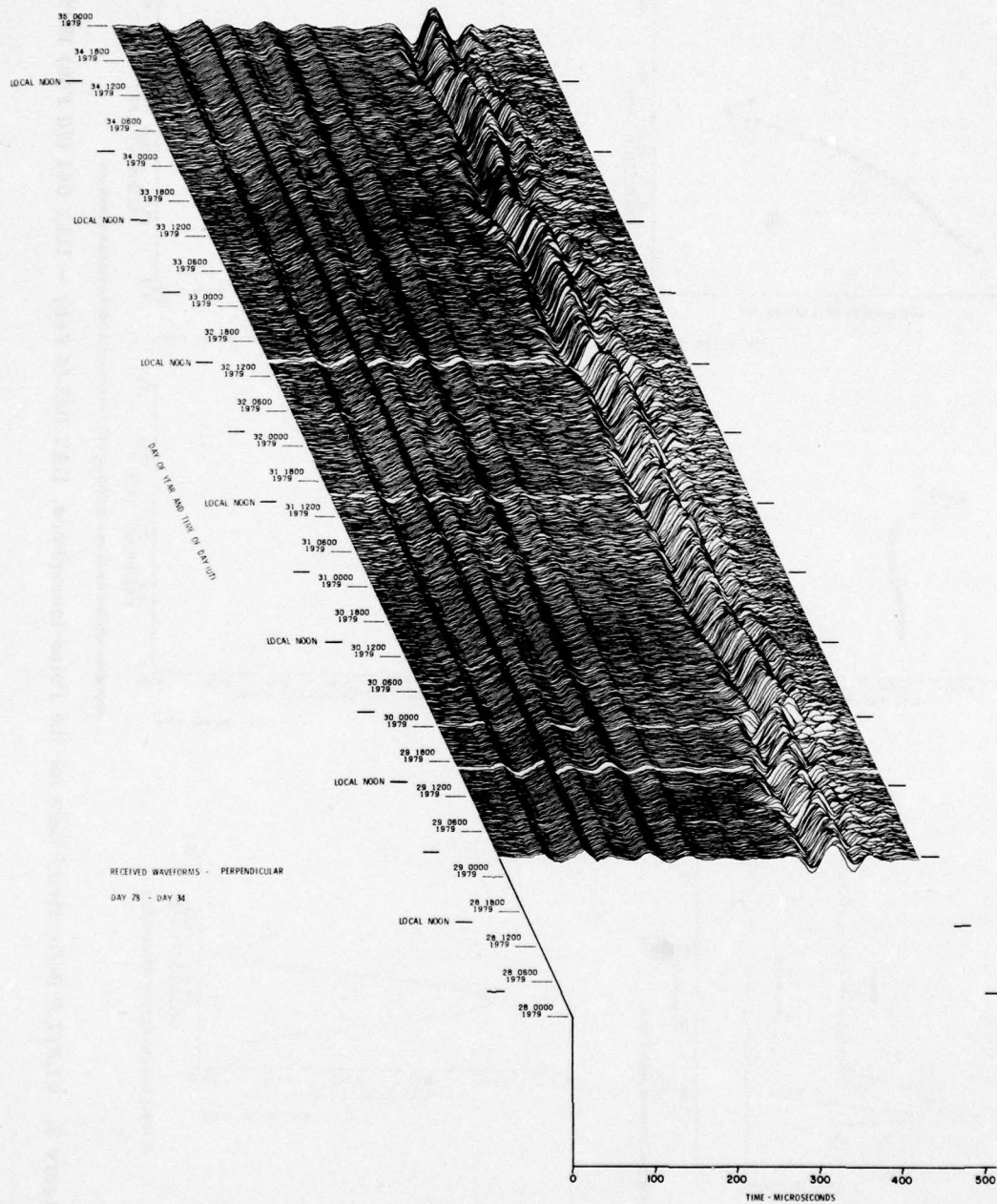


Figure 7. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 028 (28 Jan) - DAY 034 (3 Feb) 1979 (Cont)
Part S. \perp Waveform Display

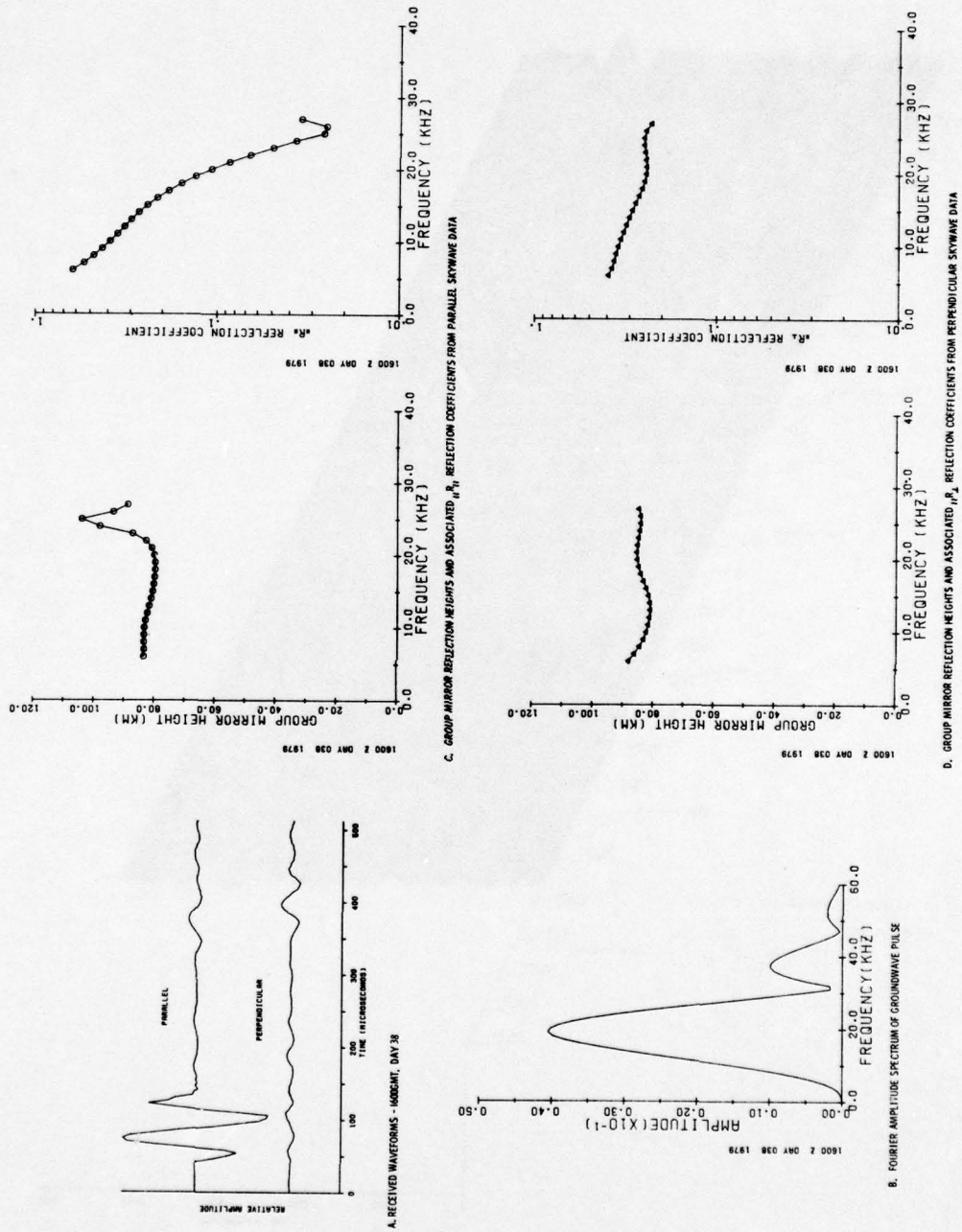


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 035 (4 Feb) - DAY 041 (10 Feb) 1979

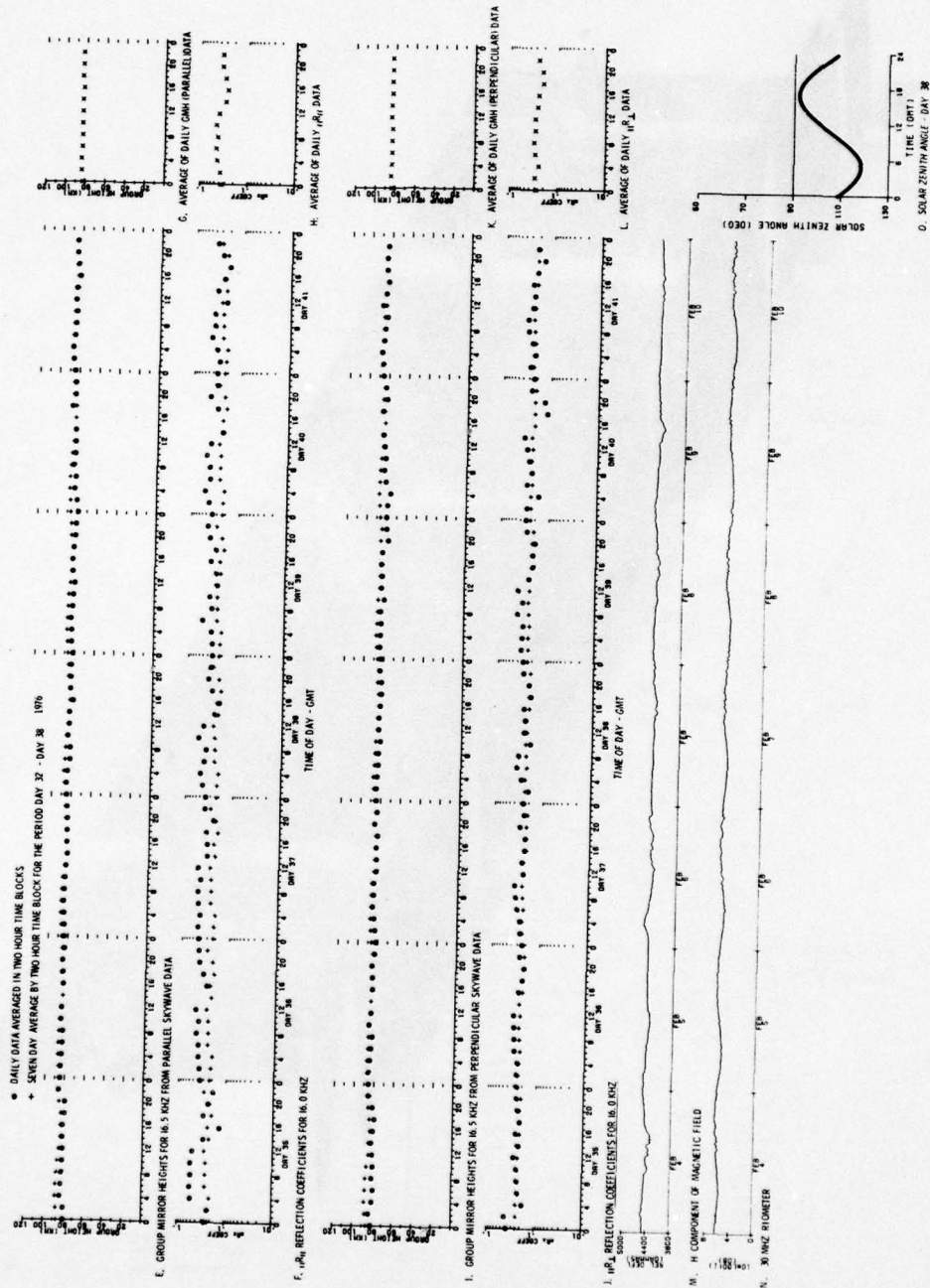


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 035 (4 Feb) - DAY 041 (10 Feb) 1979 (Cont)

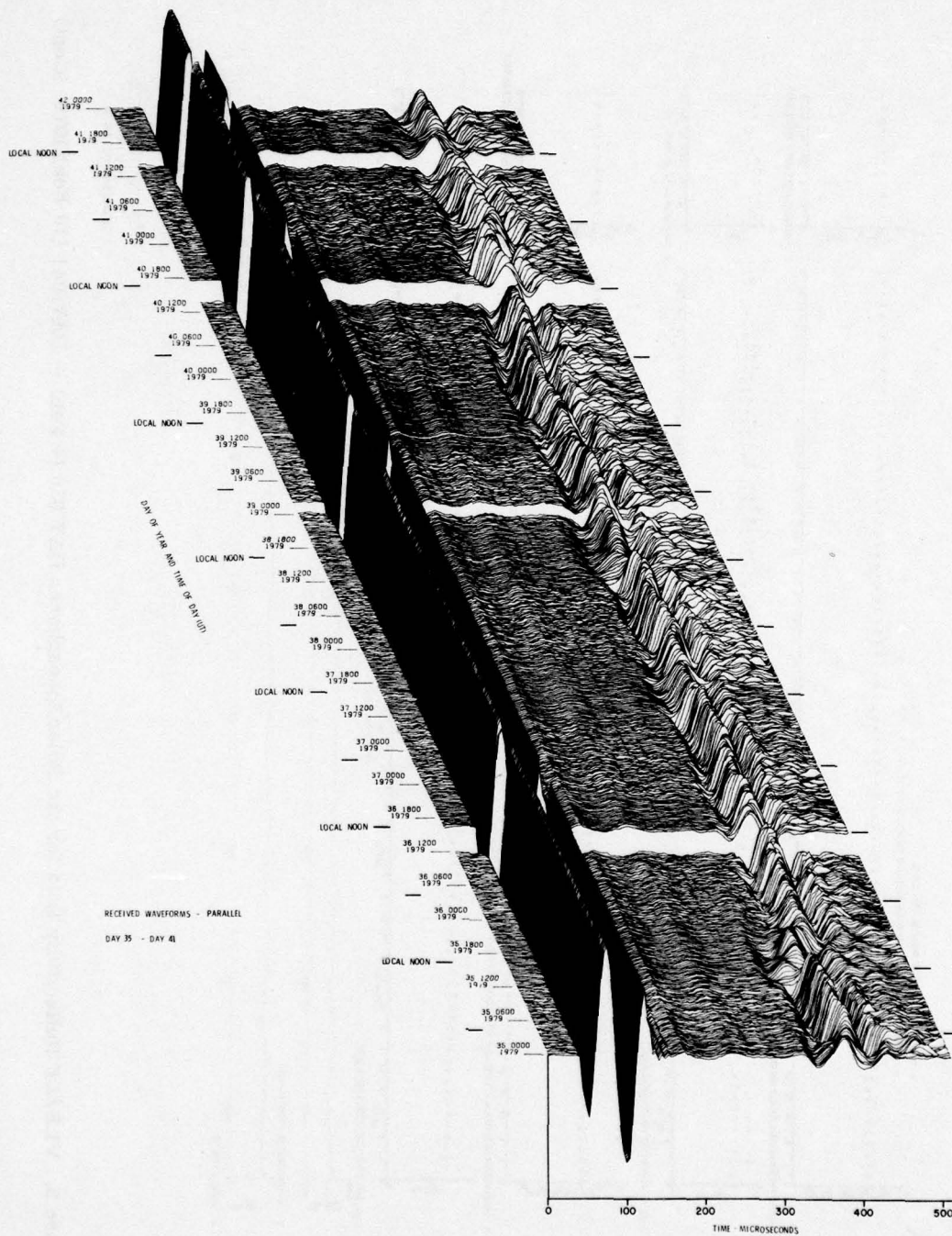


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 035 (4 Feb) - DAY 041 (10 Feb) 1979 (Cont)
 Part R. II Waveform Display

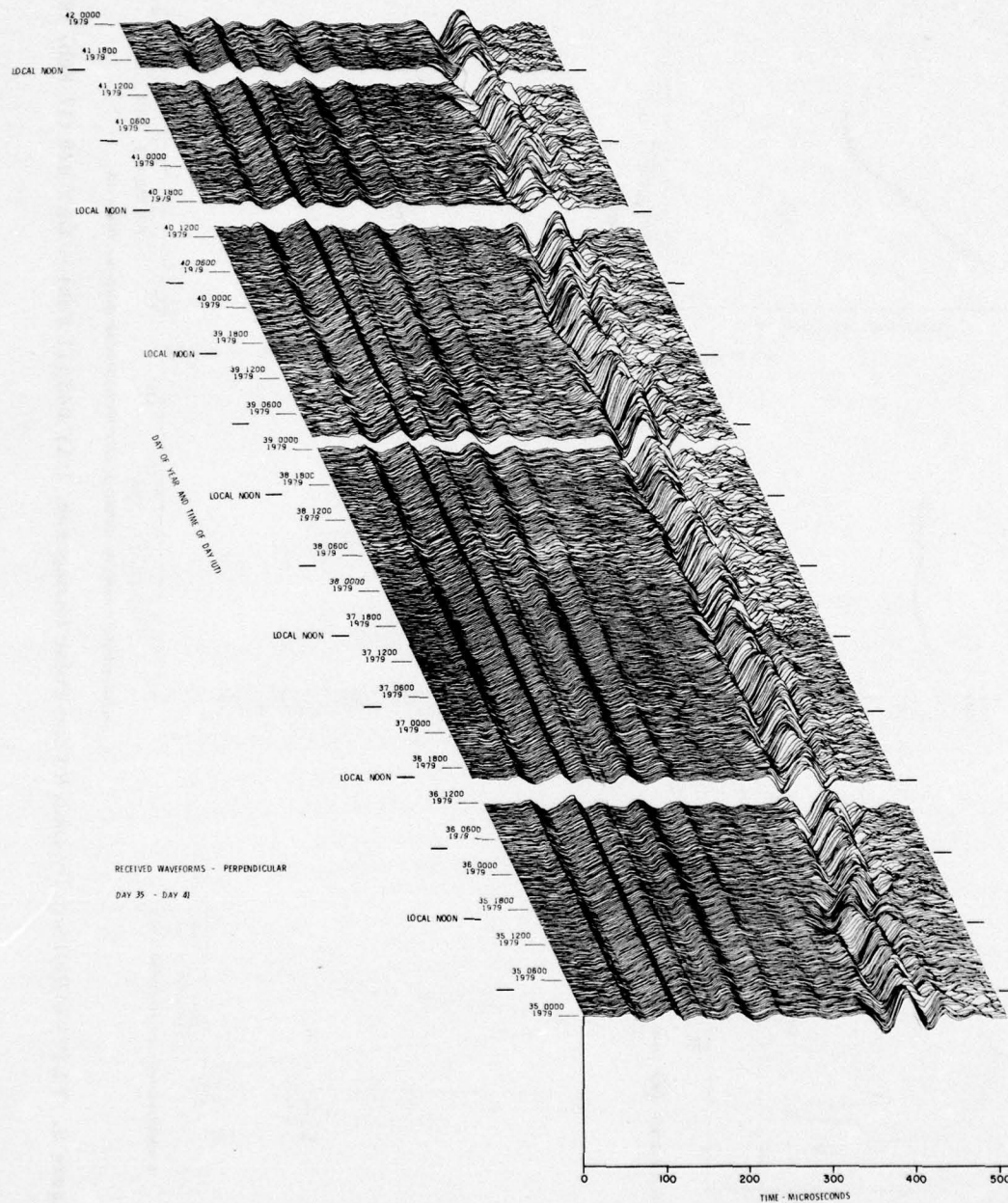


Figure 8. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 035 (4 Feb) - DAY 041 (10 Feb) 1979 (Cont)
Part S. \perp Waveform Display

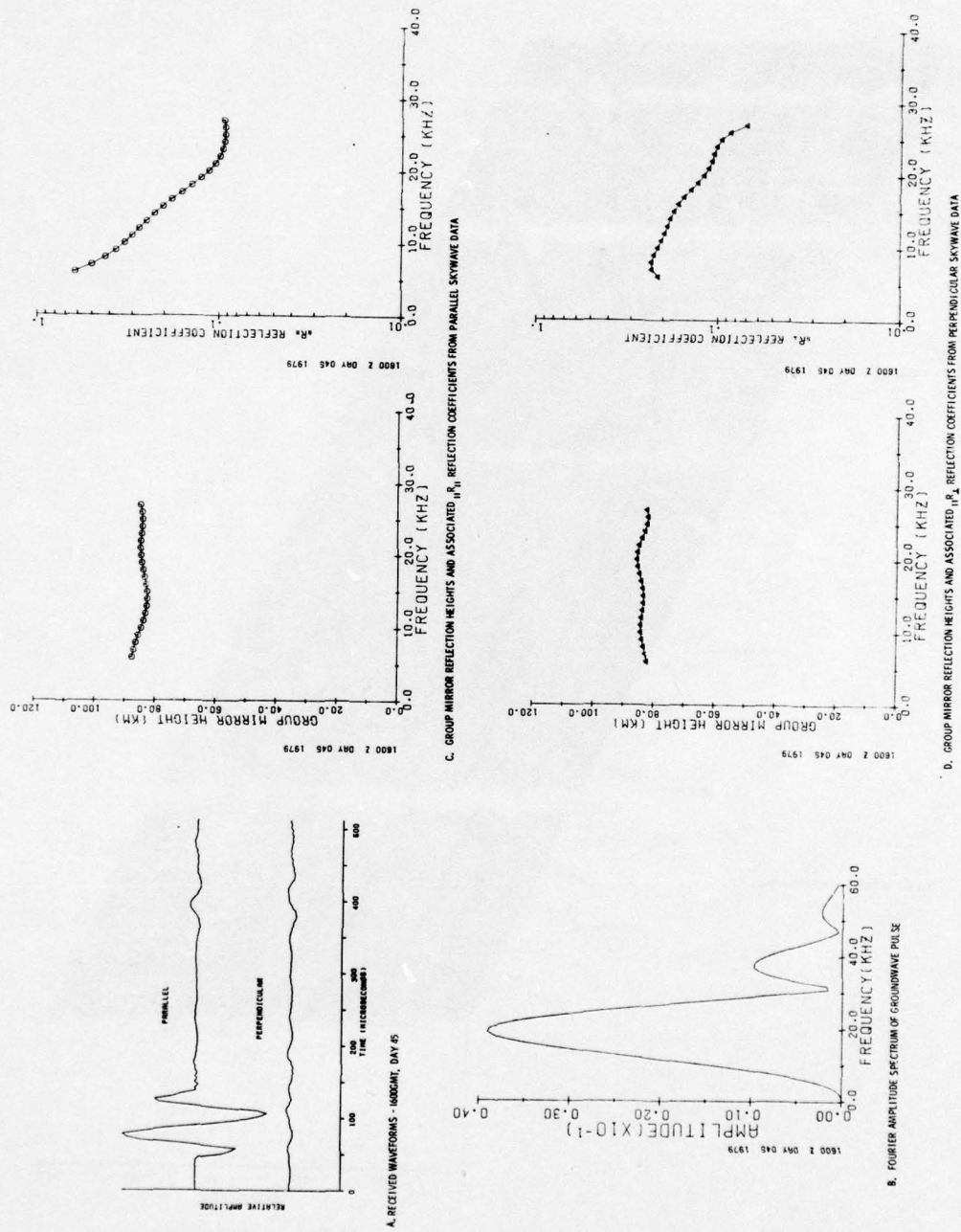


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 042 (11 Feb) - DAY 048 (17 Feb) 1979

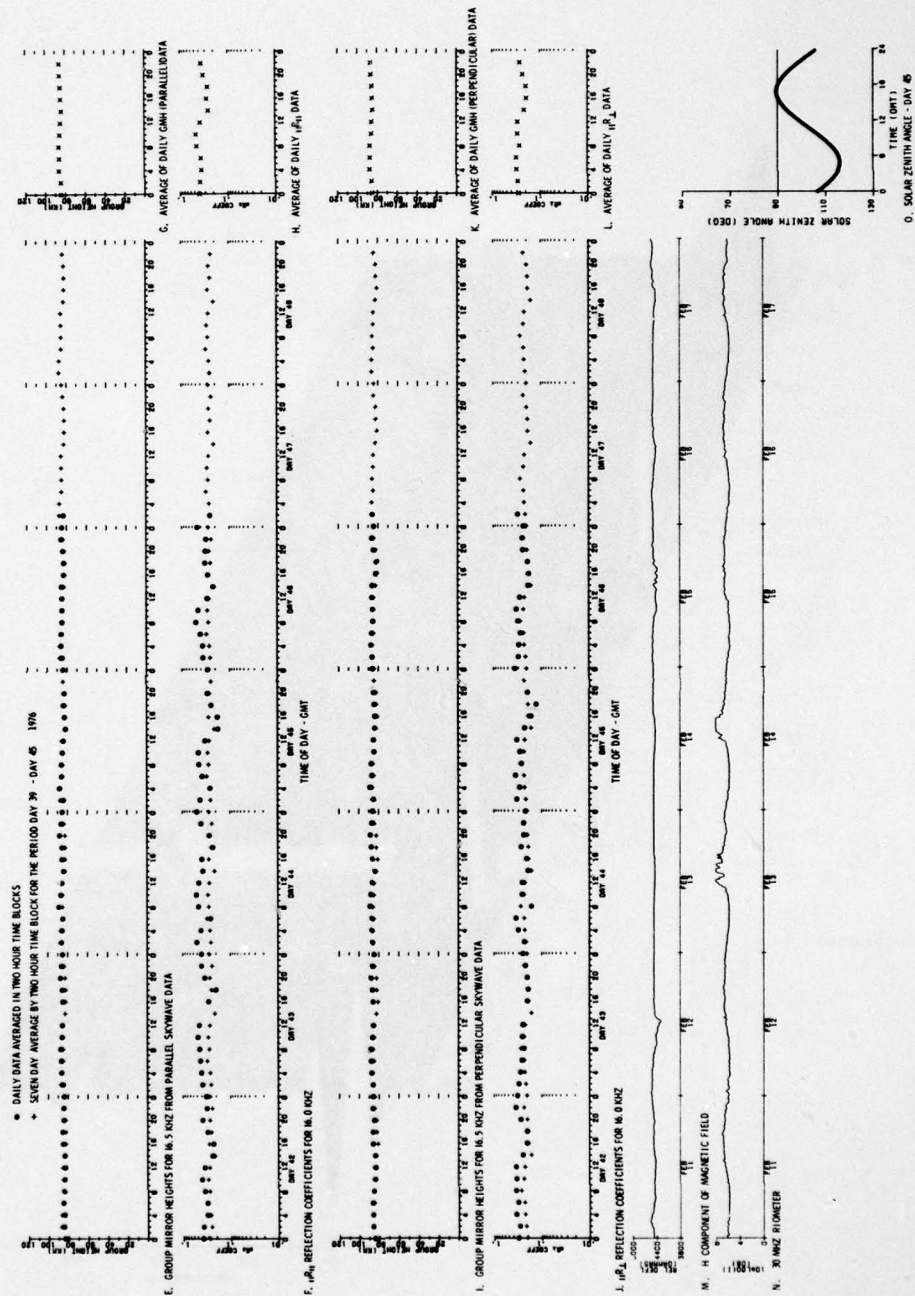


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 042 (11 Feb) - DAY 048 (17 Feb) 1979 (Cont)

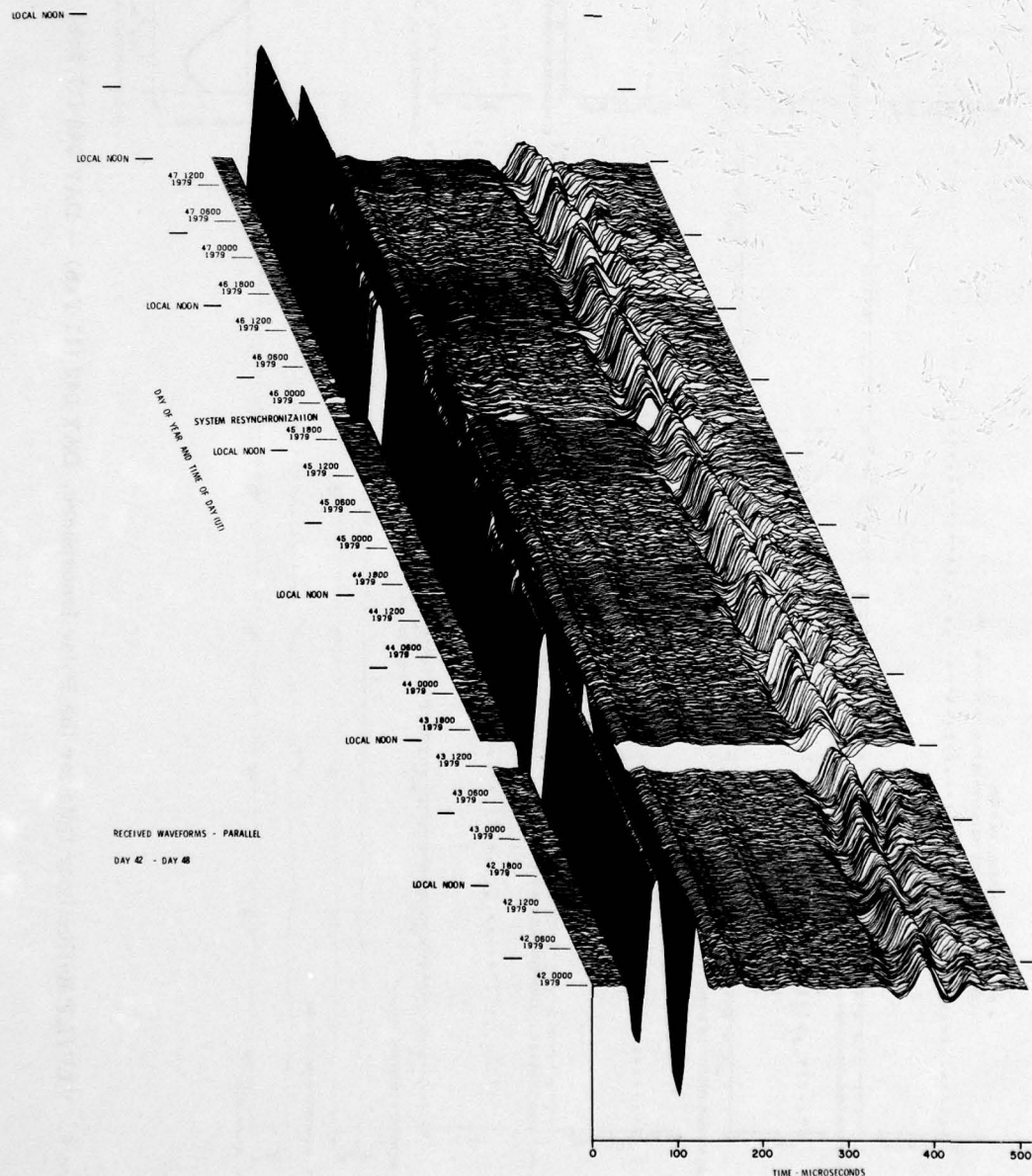


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 042 (11 Feb) - DAY 048 (17 Feb) 1979 (Cont)
Part R. II Waveform Display

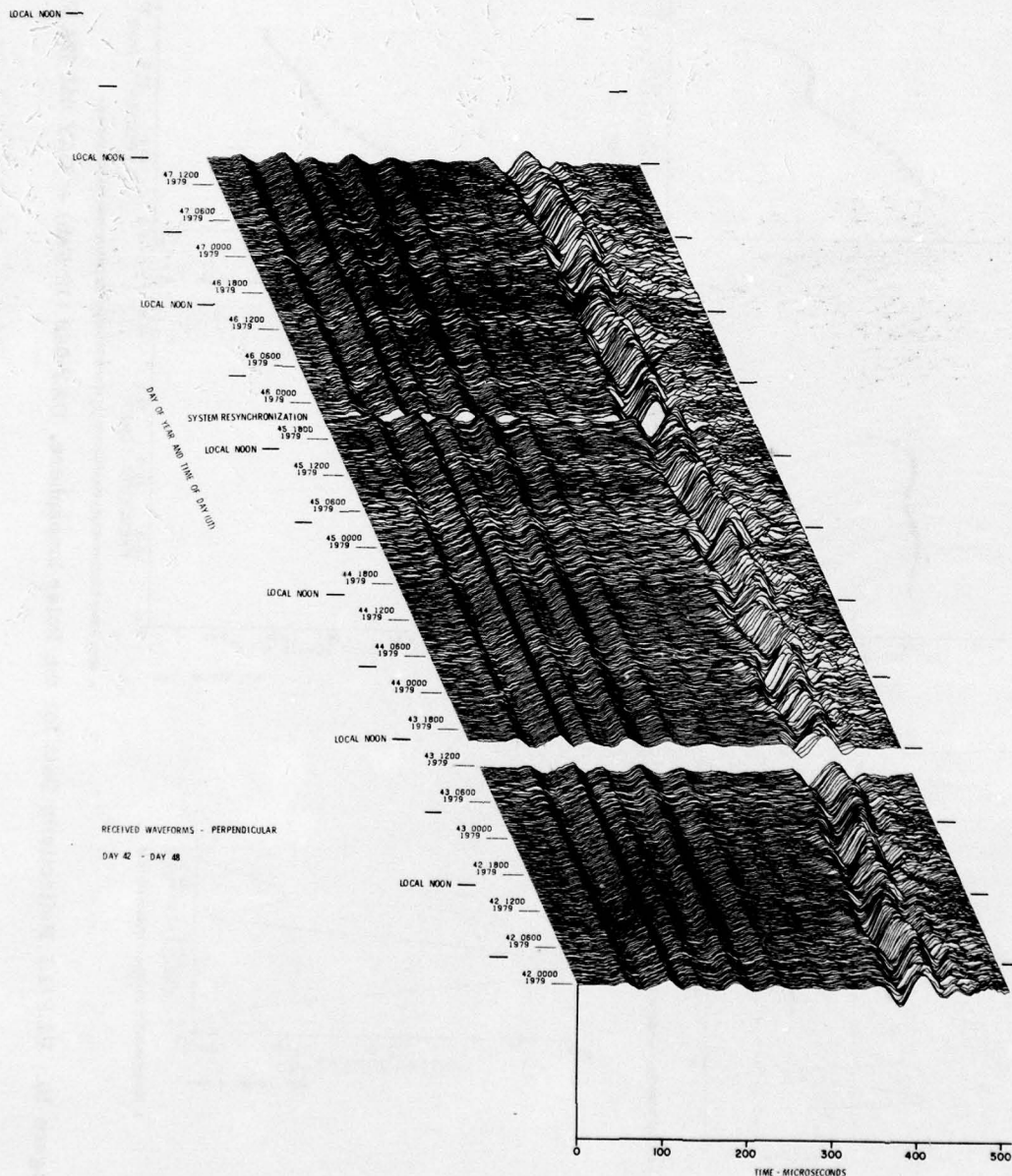


Figure 9. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 042 (11 Feb) - DAY 048 (17 Feb) 1979 (Cont)
 Part S. 1 Waveform Display

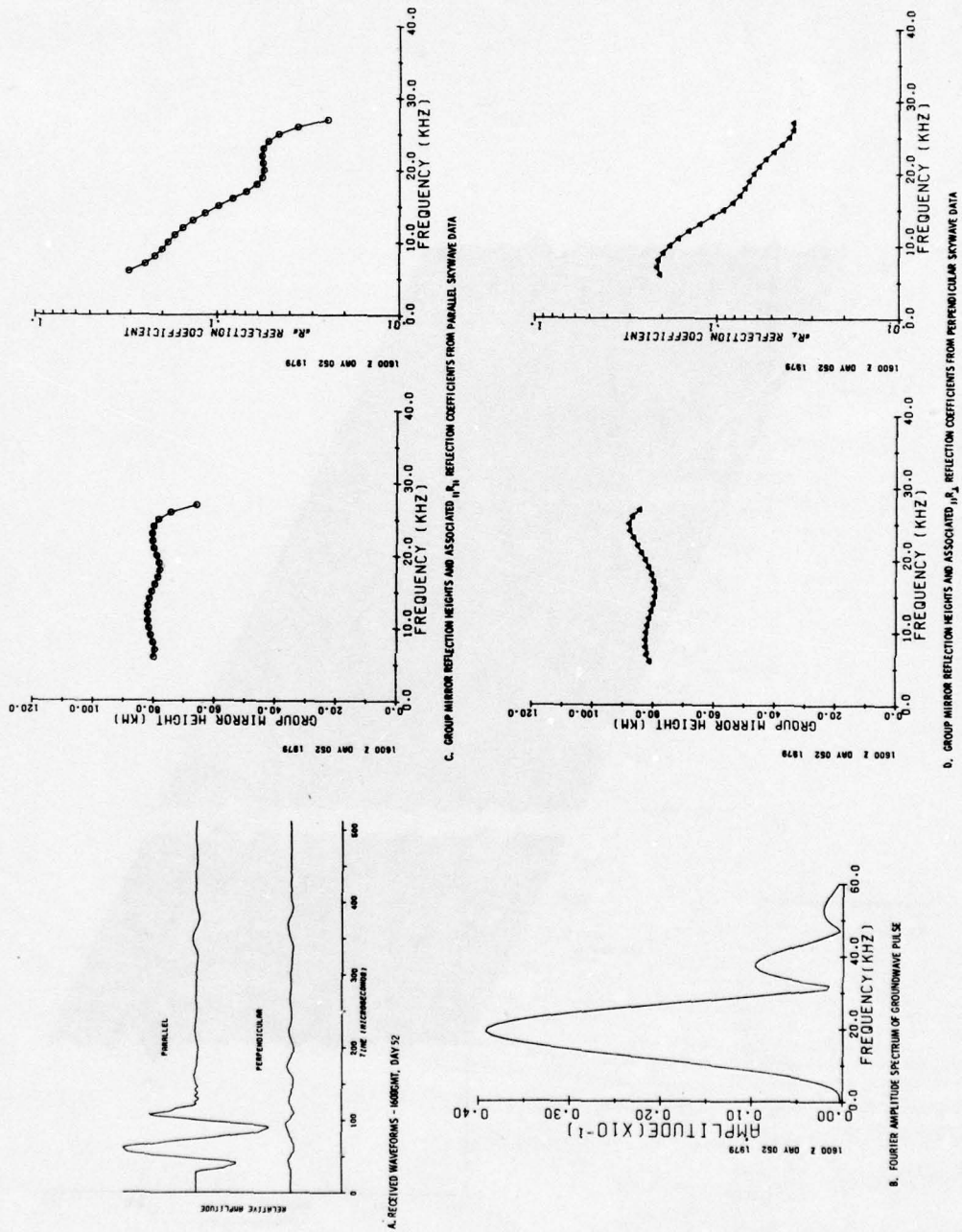


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 049 (18 Feb) - DAY 055 (24 Feb) 1979

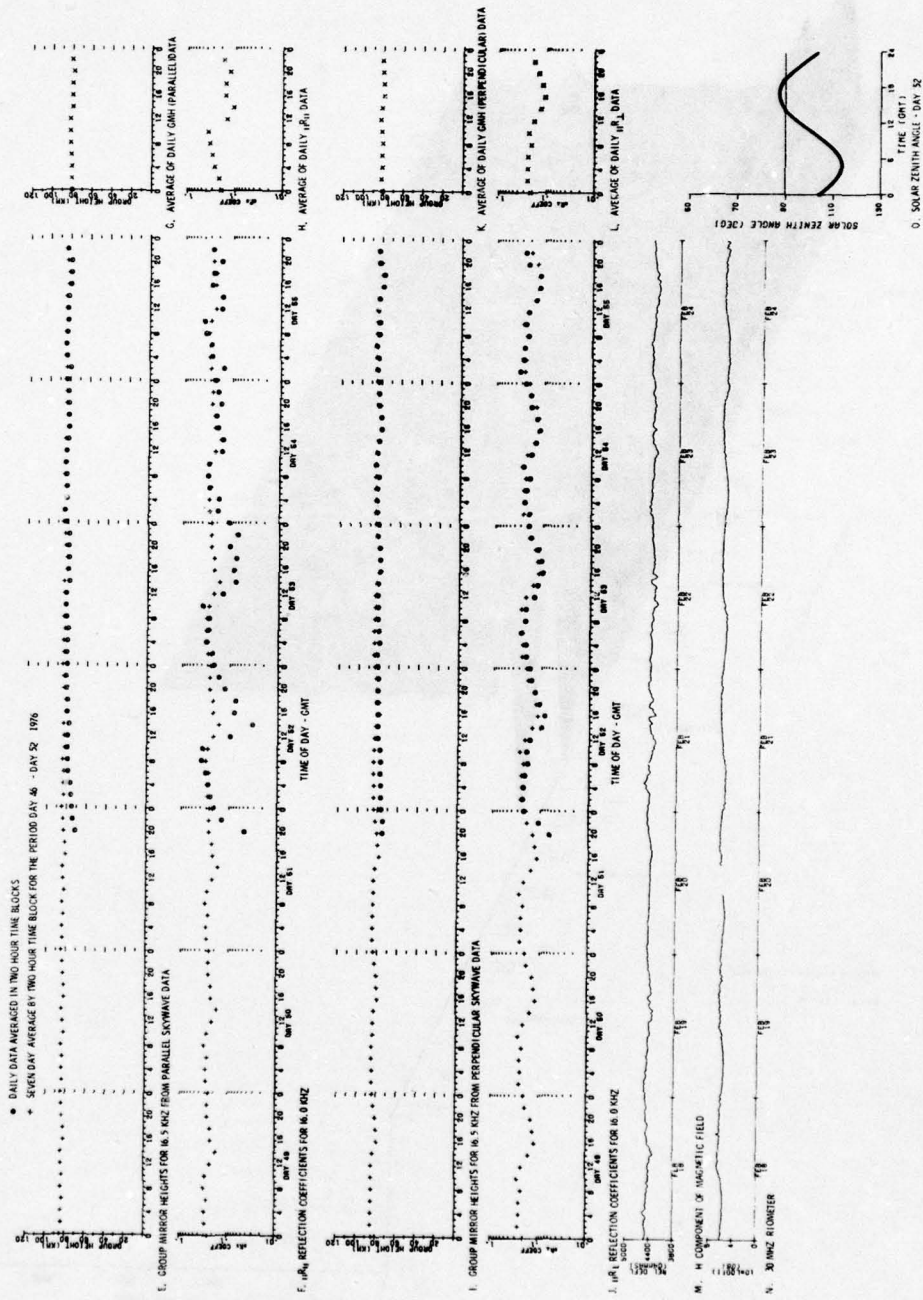


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 049 (18 Feb) - DAY 055 (24 Feb) 1979 (Cont)

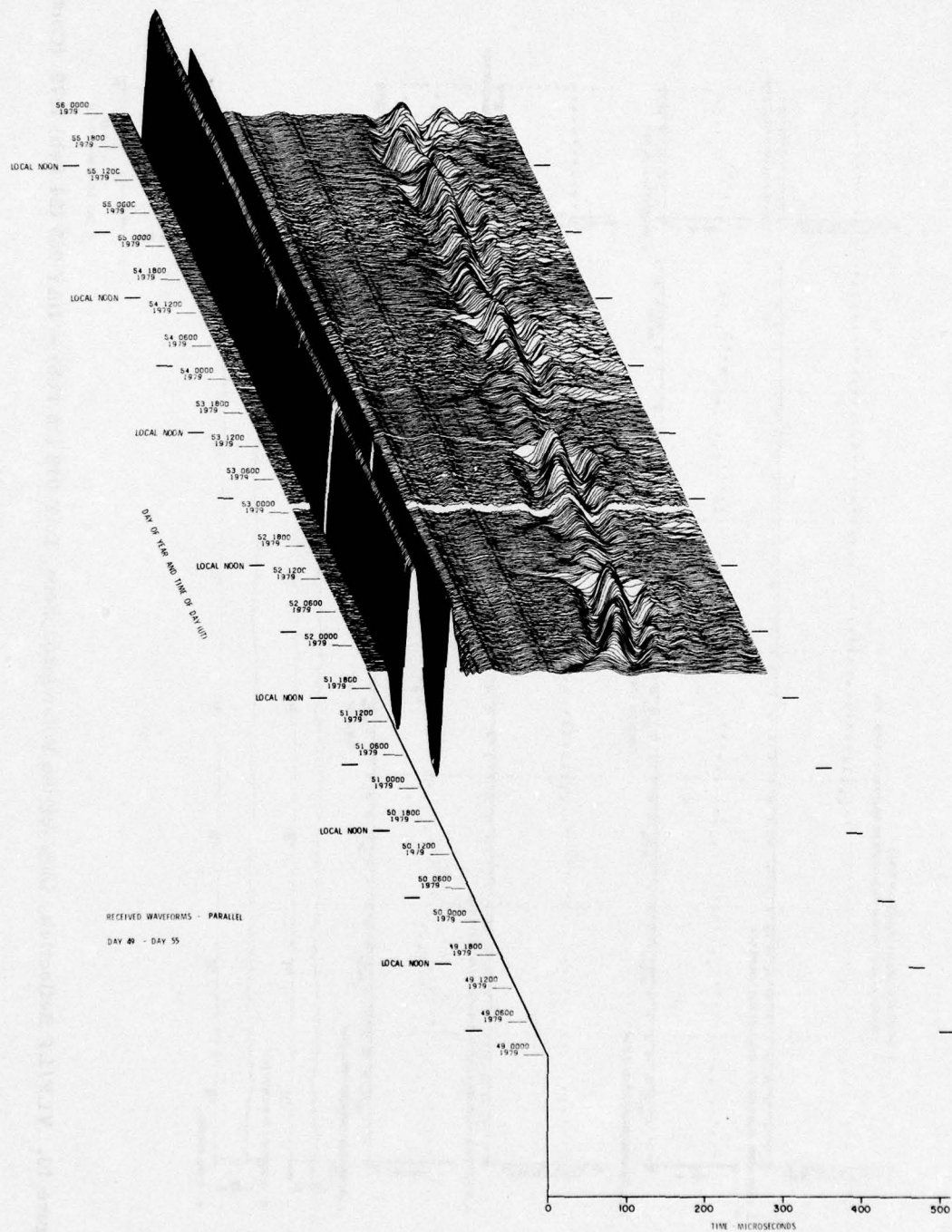


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 049 (18 Feb) - DAY 055 (24 Feb) 1979 (Cont)
Part R. II Waveform Display

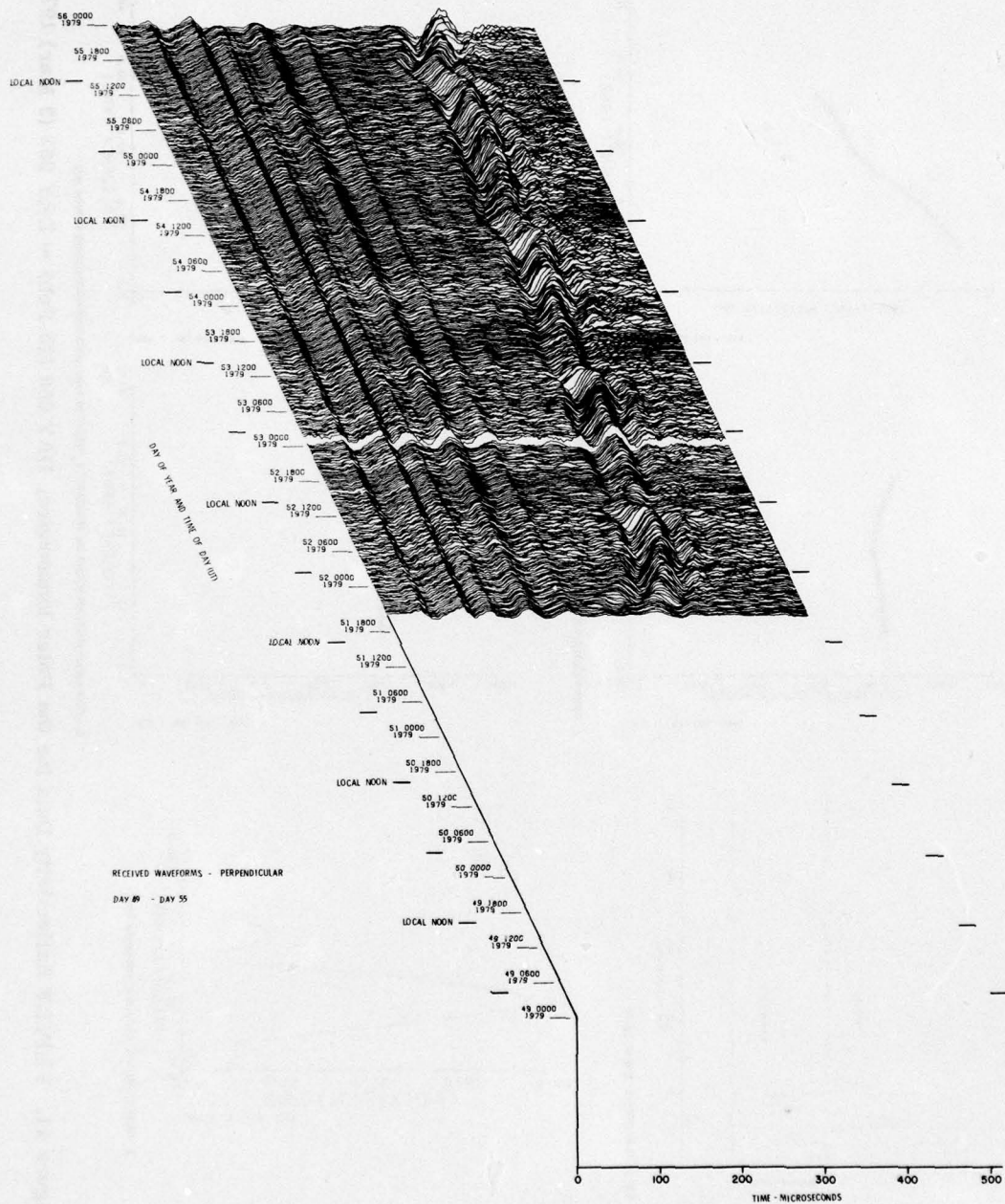


Figure 10. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 049 (18 Feb) - DAY 055 (24 Feb) 1979 (Cont)
Part S. \perp Waveform Display

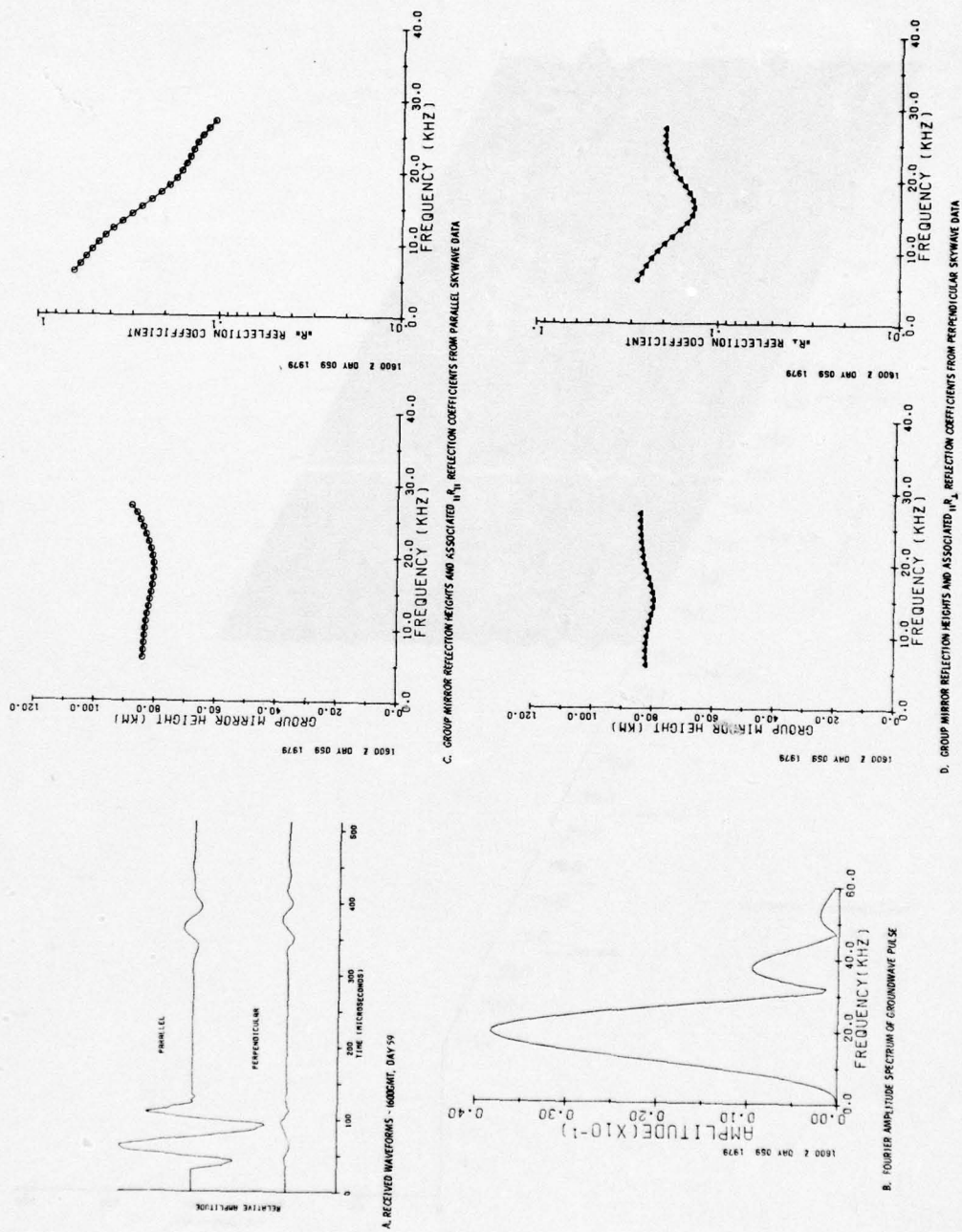


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 056 (25 Feb) - DAY 062 (3 Mar) 1979

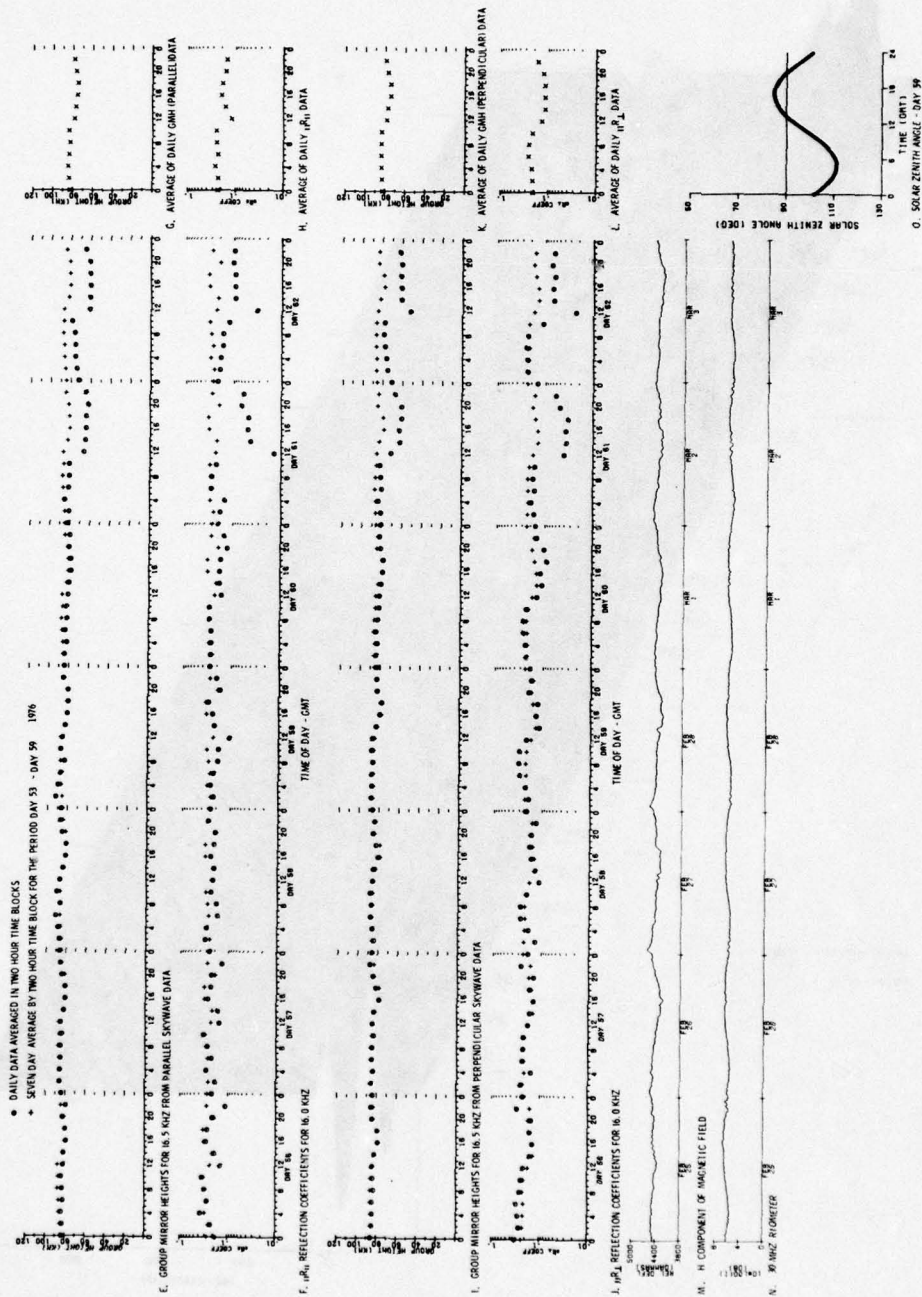


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 056 (25 Feb) - DAY 062 (3 Mar) 1979 (Cont)

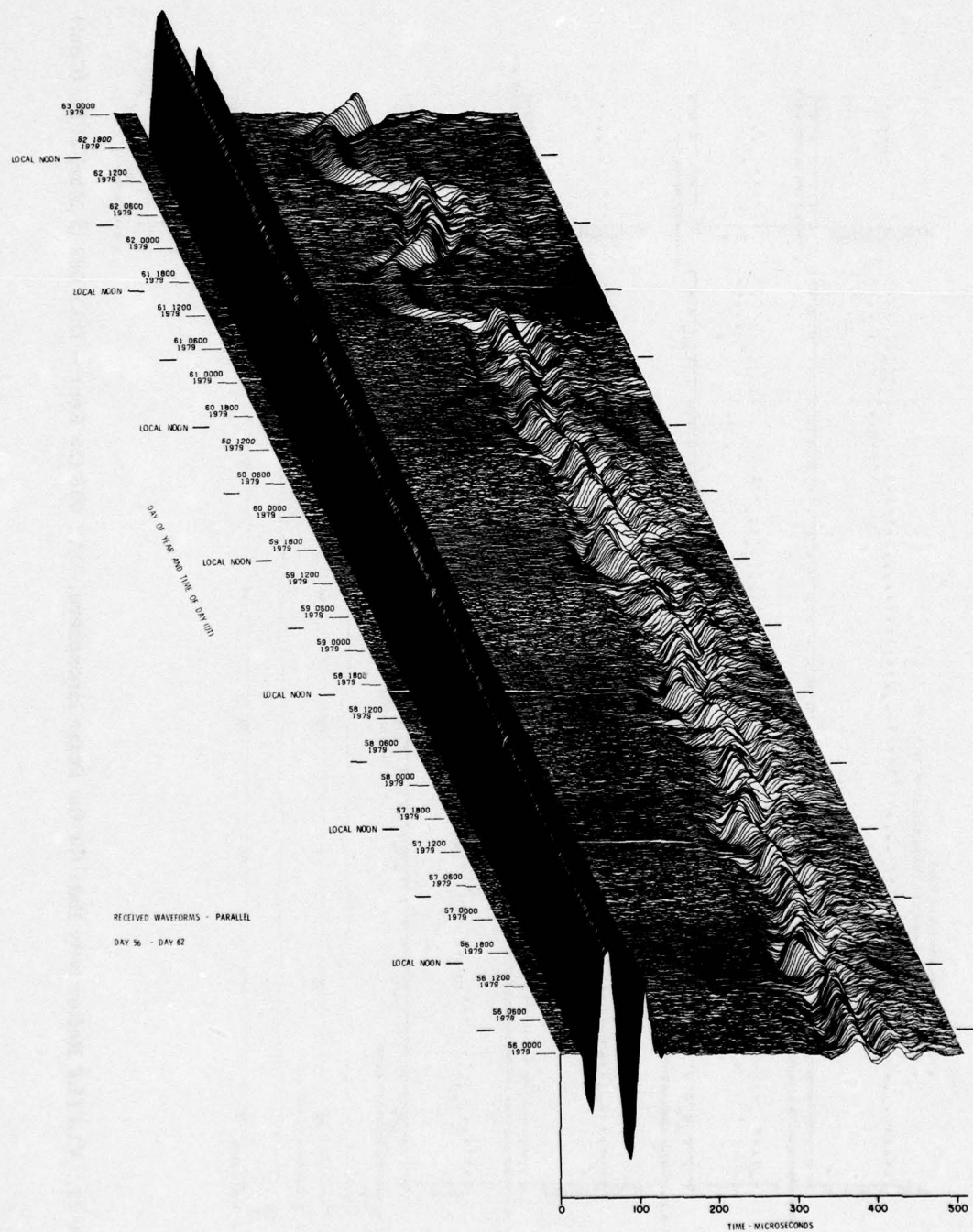


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 056 (25 Feb) - DAY 062 (3 Mar) 1979 (Cont)
 Part R. II Waveform Display

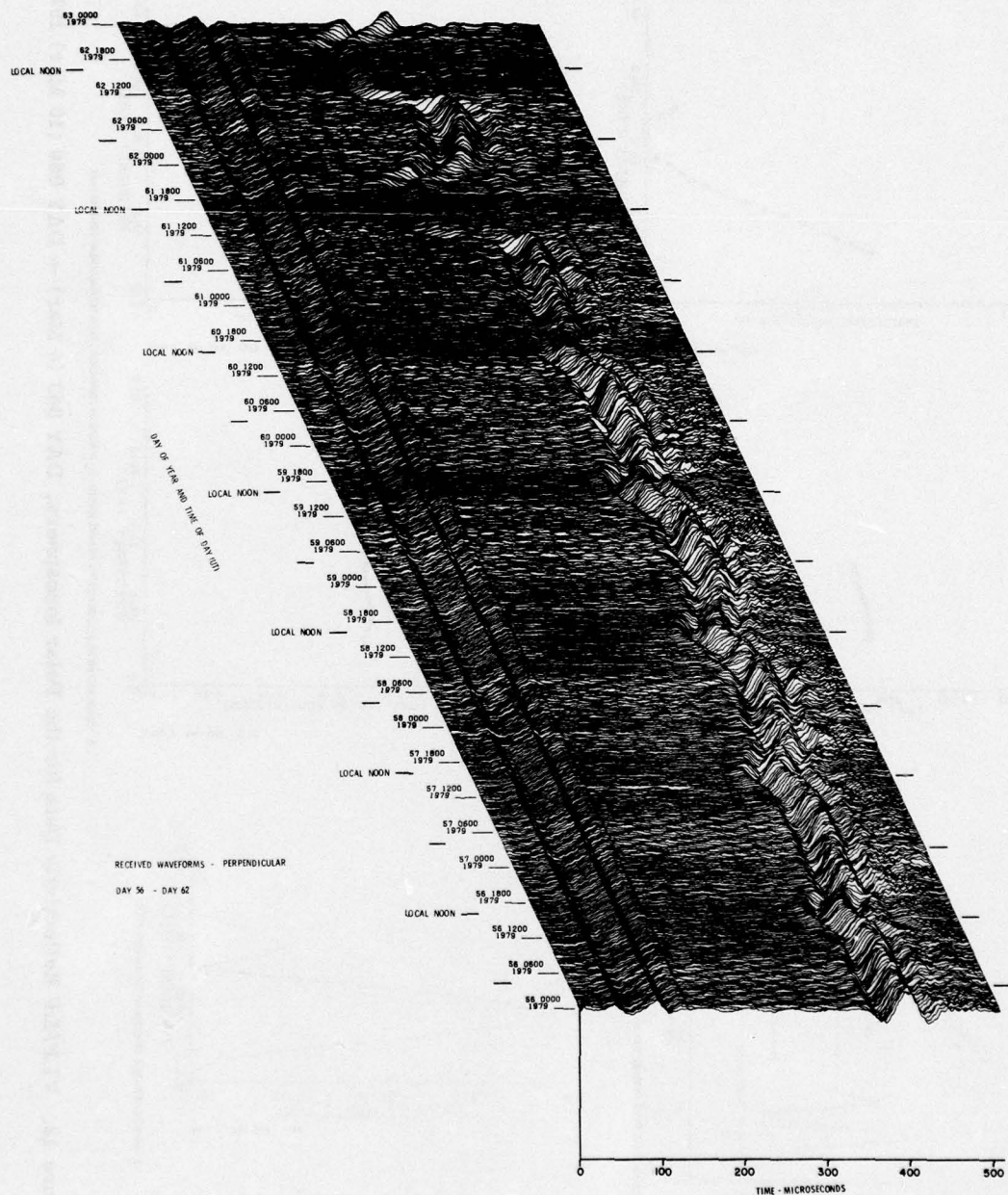


Figure 11. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 056 (25 Feb) - DAY 062 (3 Mar) 1979 (Cont)
Part S. \perp Waveform Display

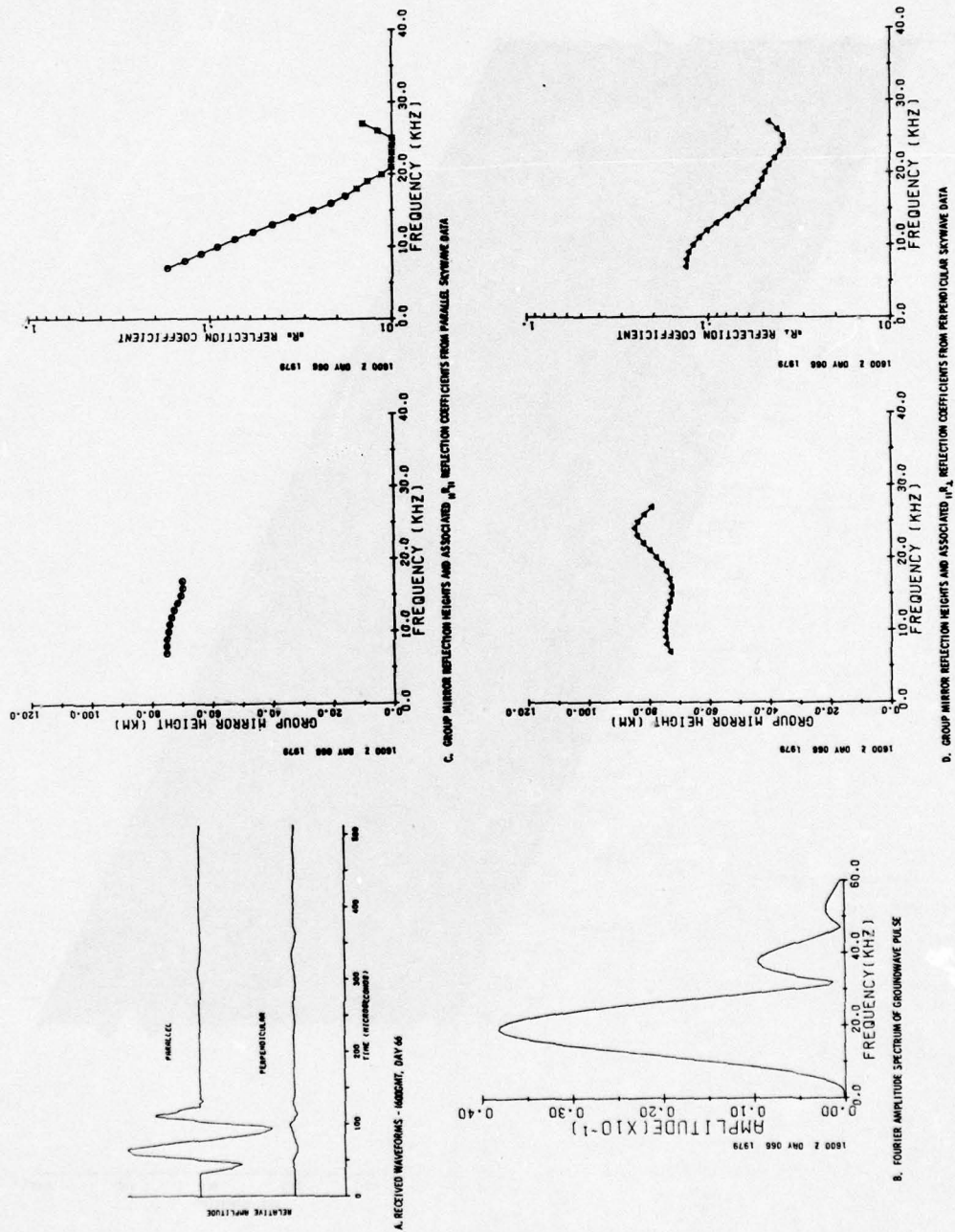


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 063 (4 Mar) - DAY 069 (10 Mar) 1979

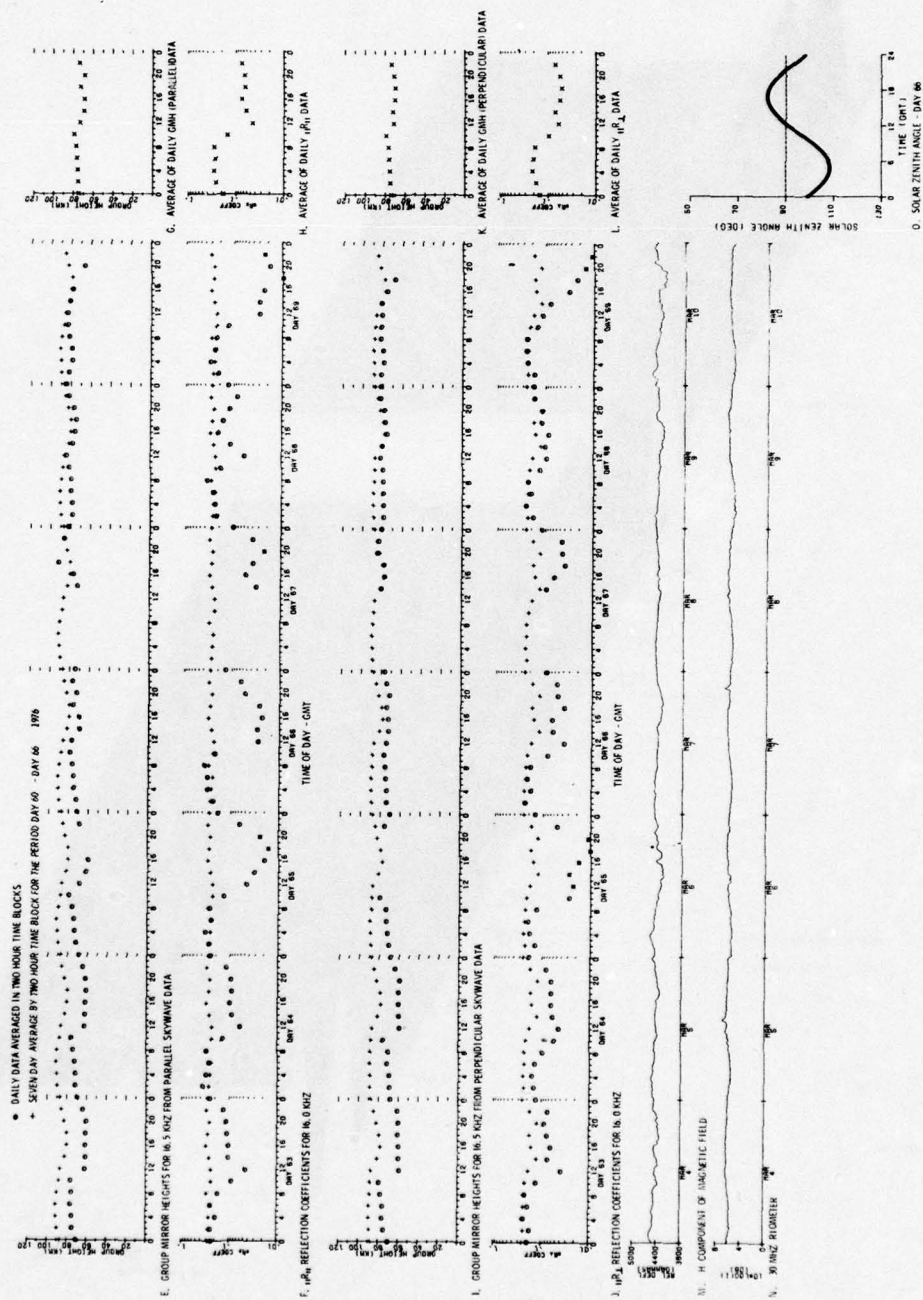


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 063 (4 Mar) - DAY 069 (10 Mar) 1979 (Cont)

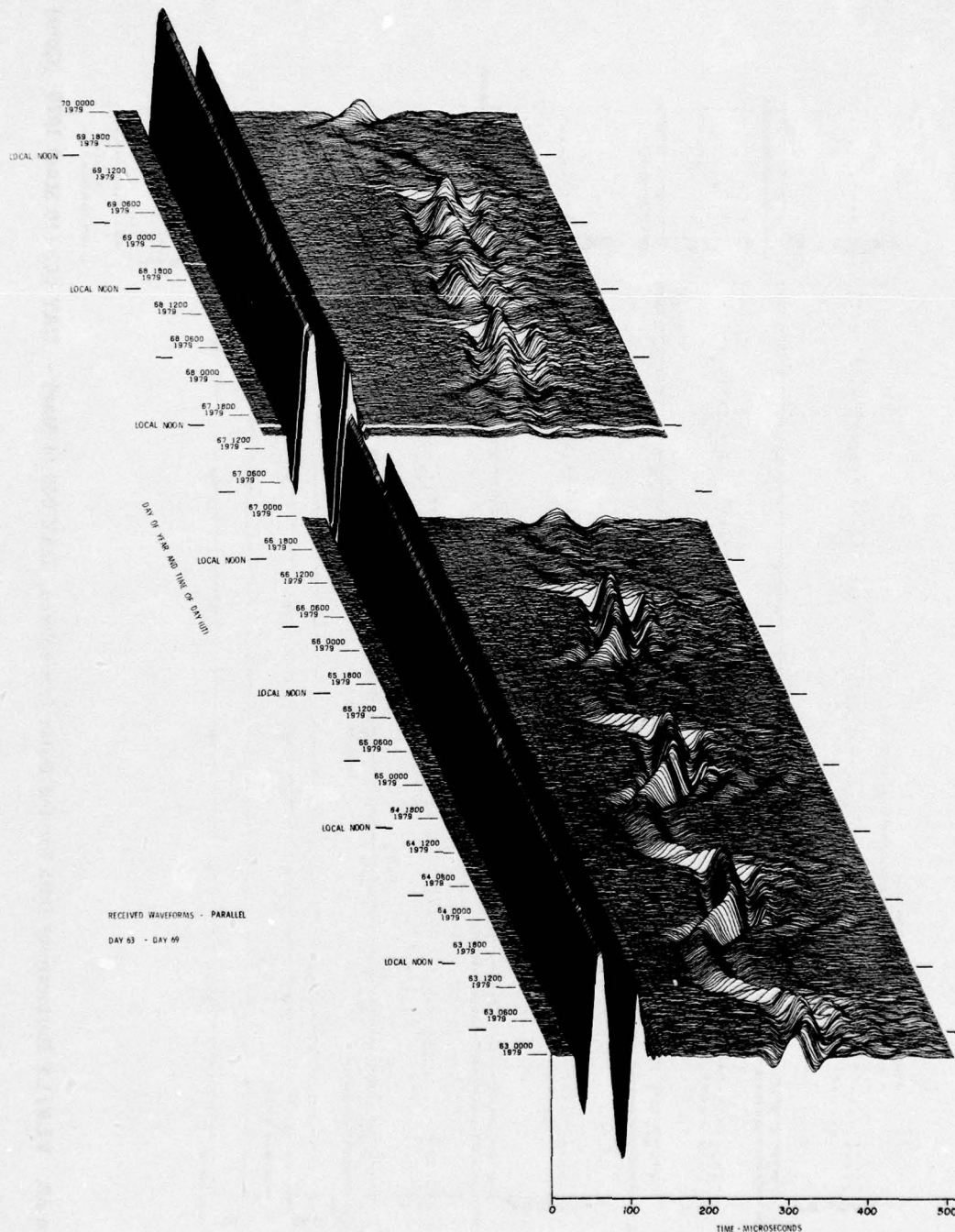


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 063 (4 Mar) - DAY 069 (10 Mar) 1979 (Cont)
Part R. II Waveform Display

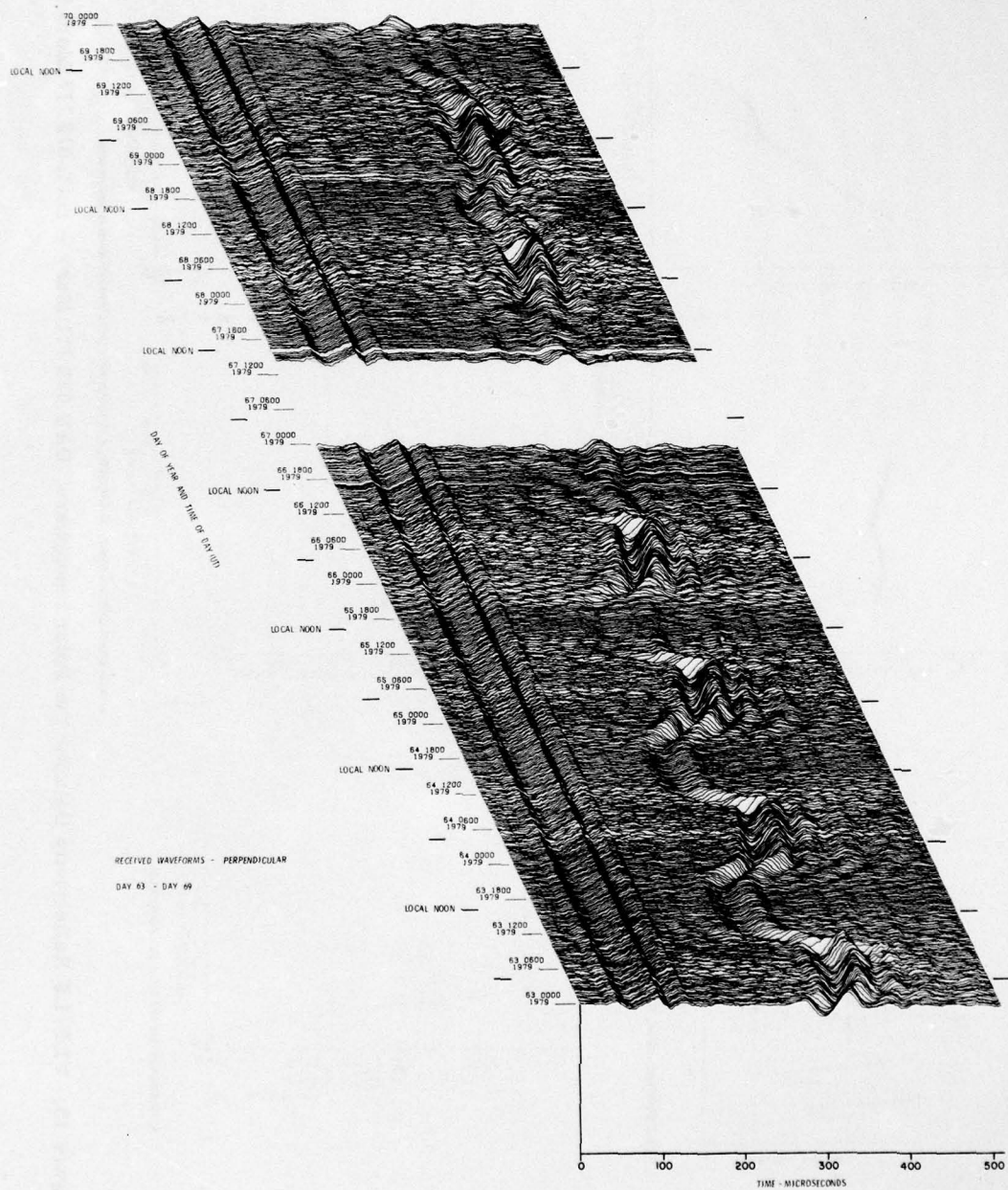


Figure 12. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 063 (4 Mar) - DAY 069 (10 Mar) 1979 (Cont)
Part S. \perp Waveform Display

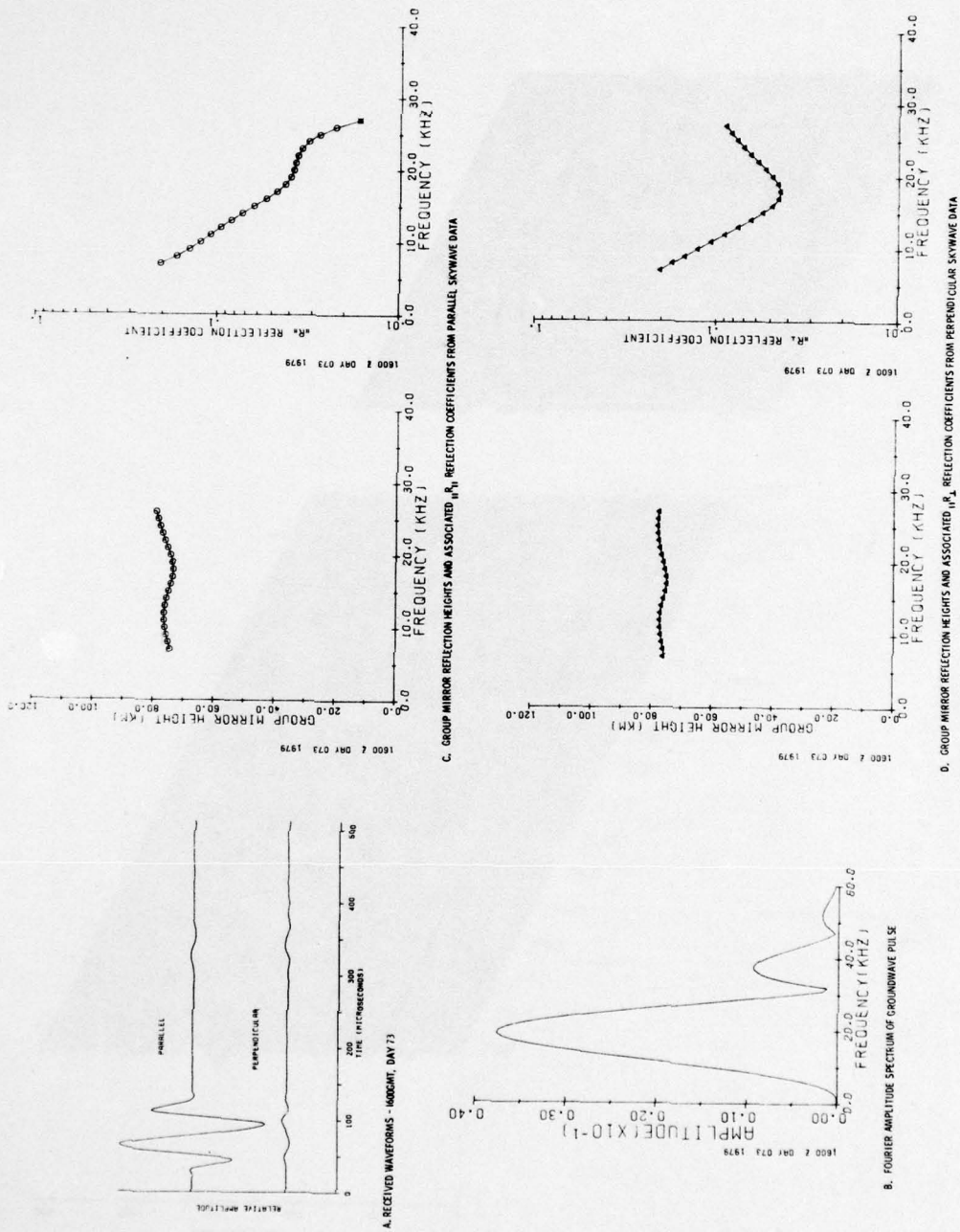


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 070 (11 Mar) - DAY 076 (17 Mar) 1979

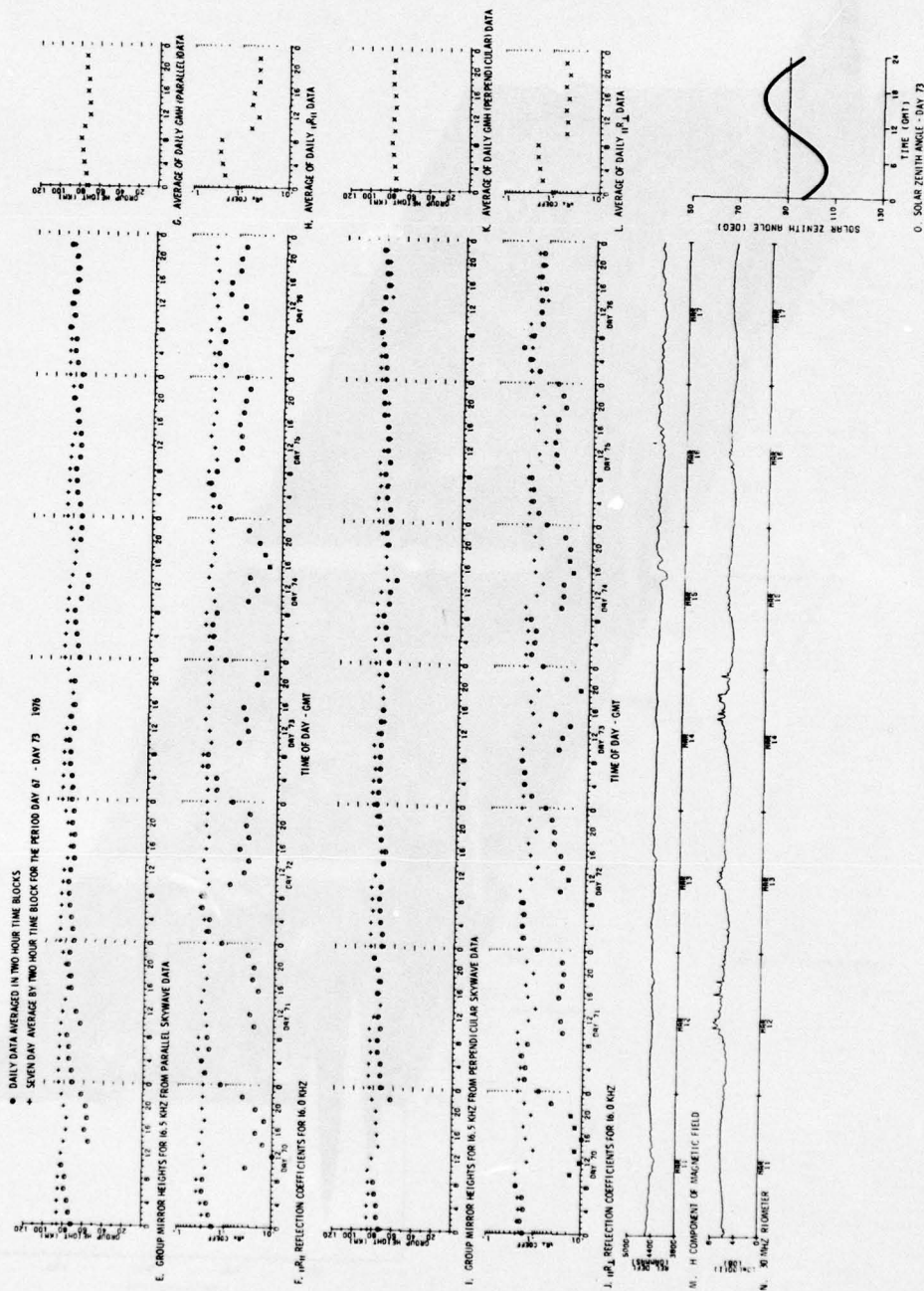


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 070 (11 Mar) - DAY 076 (17 Mar) 1979 (Cont)

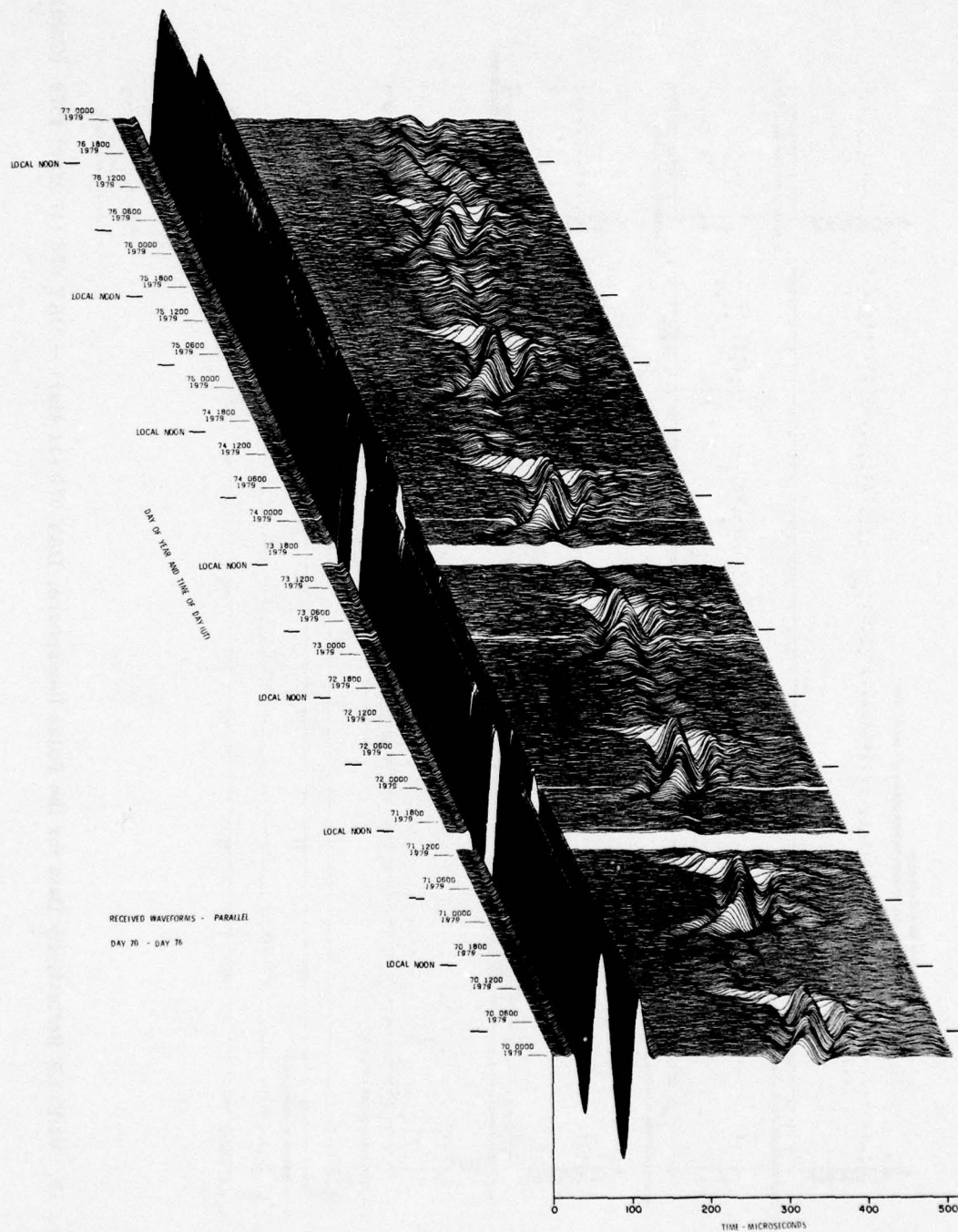


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 070 (11 Mar) - DAY 076 (17 Mar) 1979 (Cont)
Part R. II Waveform Display

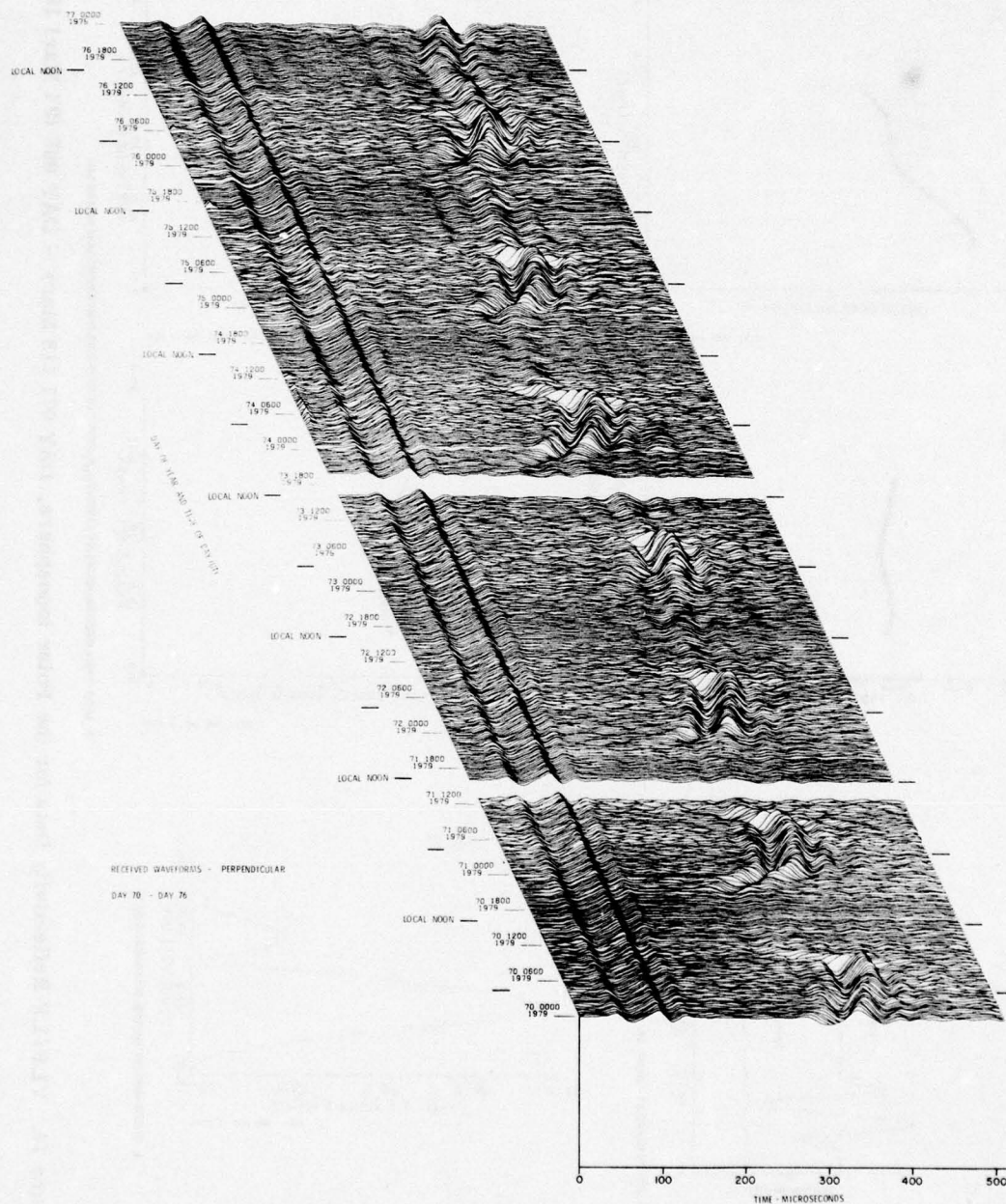


Figure 13. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 070 (11 Mar) - DAY 076 (17 Mar) 1979 (Cont)
Part S. \perp Waveform Display

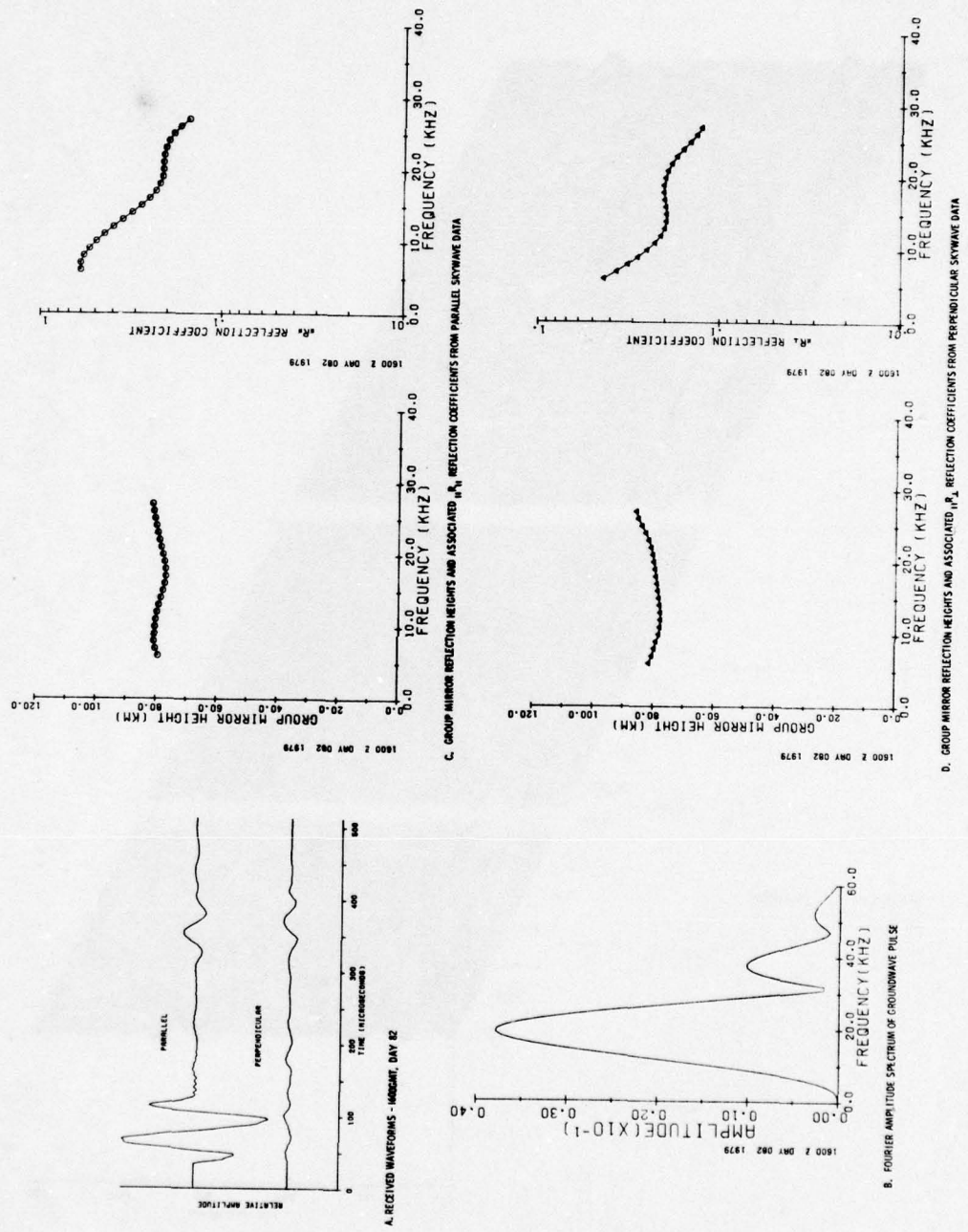
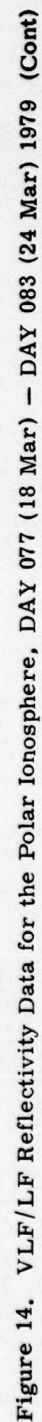


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 077 (18 Mar) - DAY 083 (24 Mar) 1979



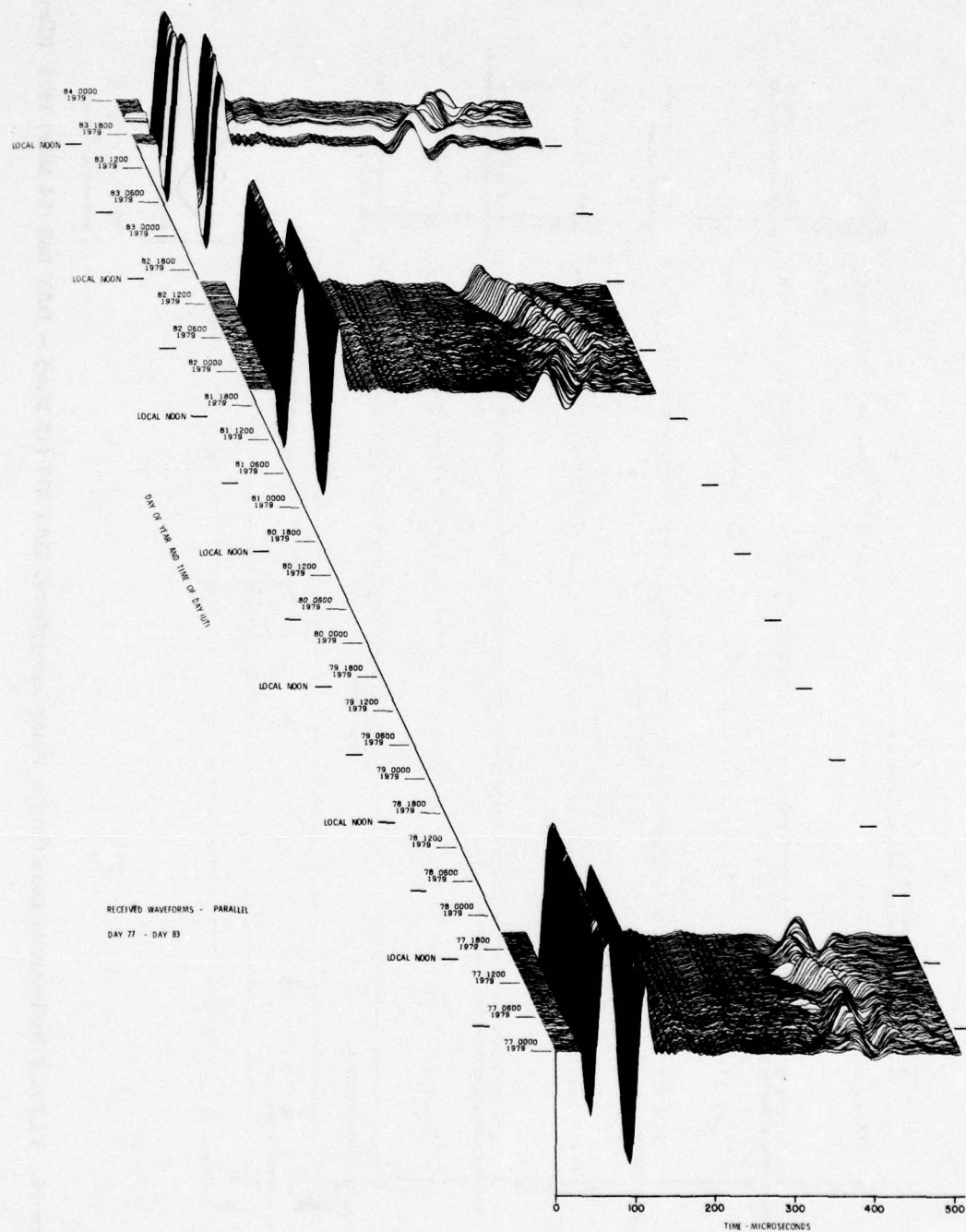


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 077 (18 Mar) - DAY 083 (24 Mar) 1979 (Cont)
Part R. II Waveform Display

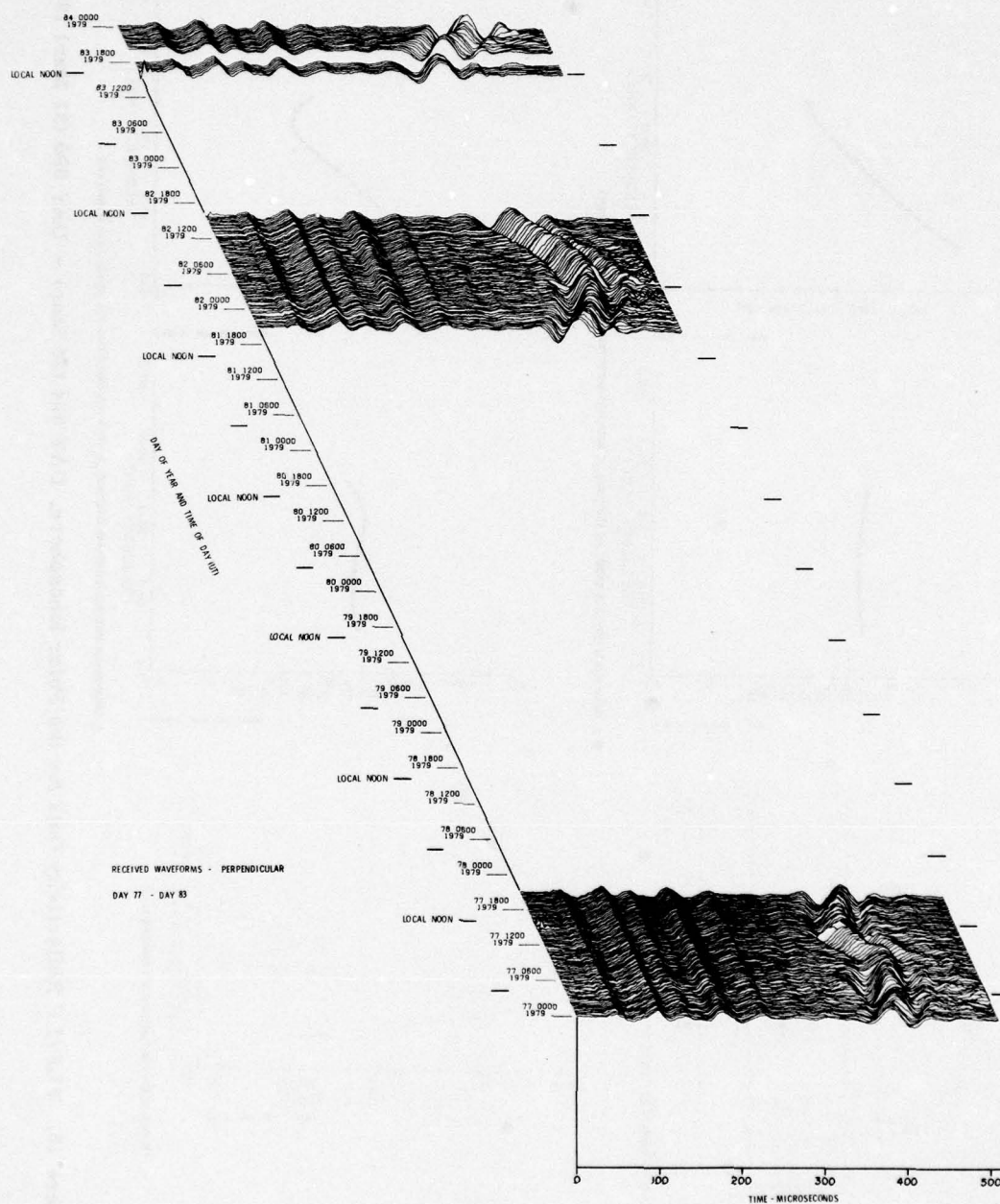


Figure 14. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 077 (18 Mar) - DAY 083 (24 Mar) 1979 (Cont)
Part S. \perp Waveform Display

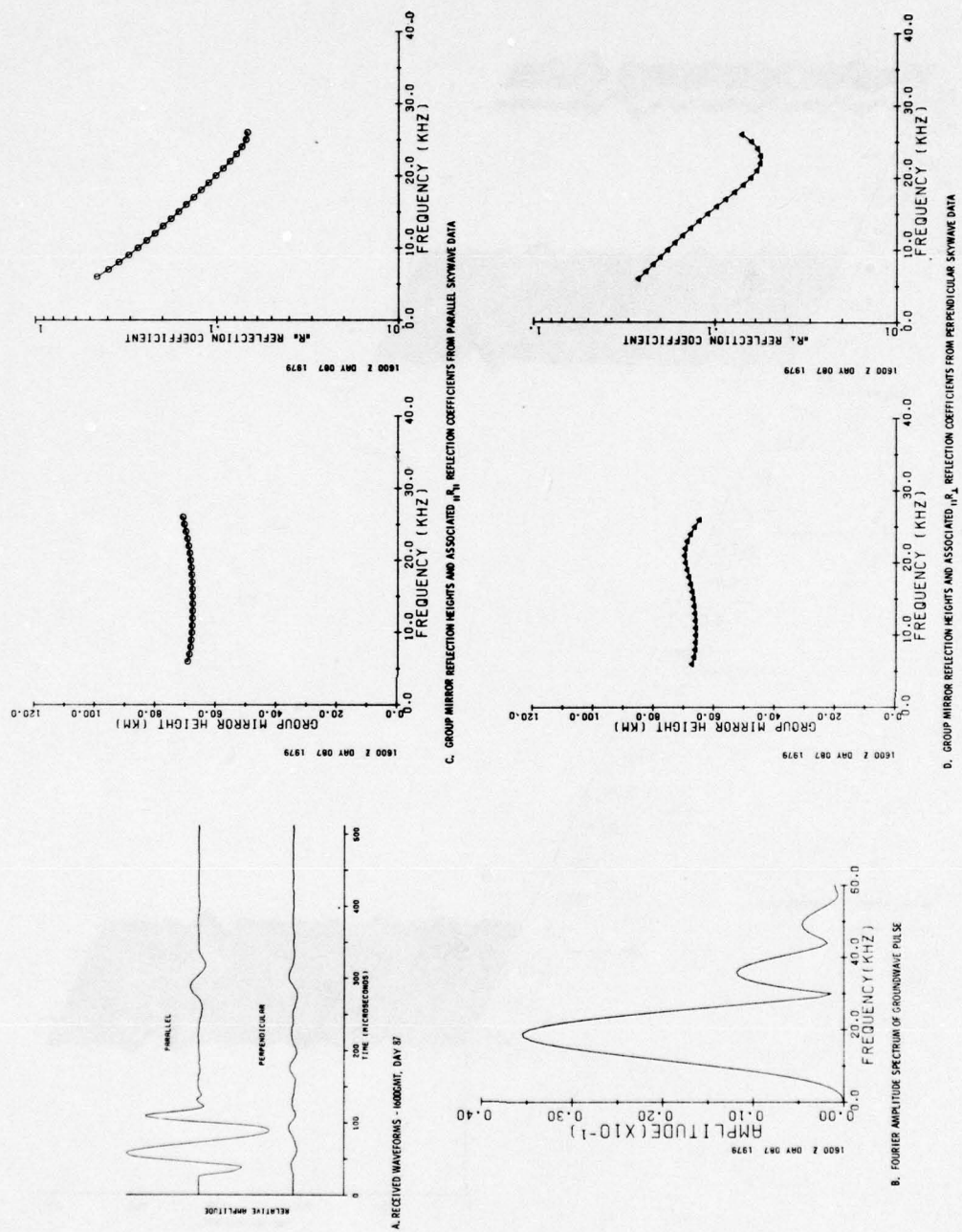


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 084 (25 Mar) - DAY 090 (31 Mar) 1979

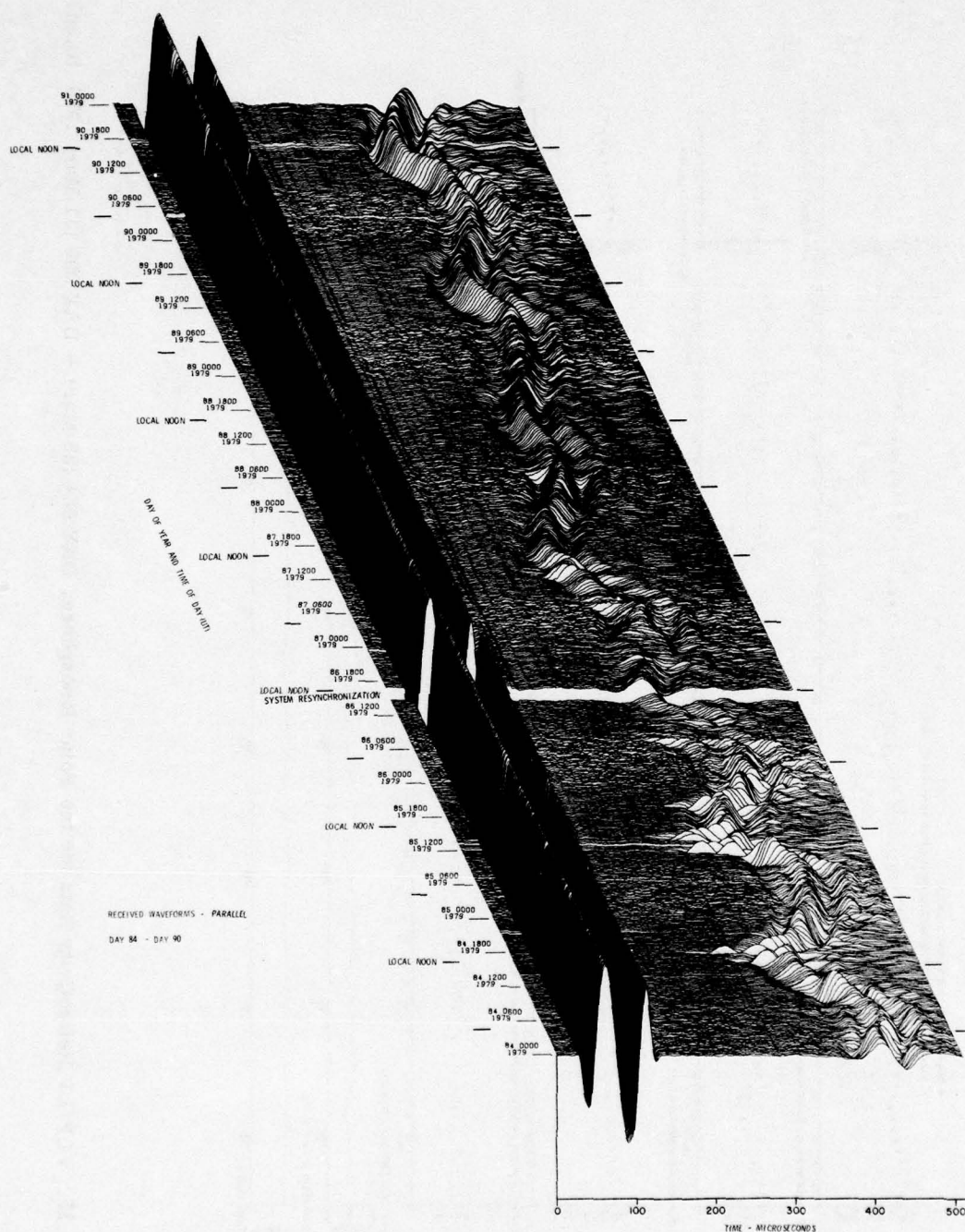


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 084 (25 Mar) - DAY 090 (31 Mar) 1979 (Cont)
 Part R. || Waveform Display

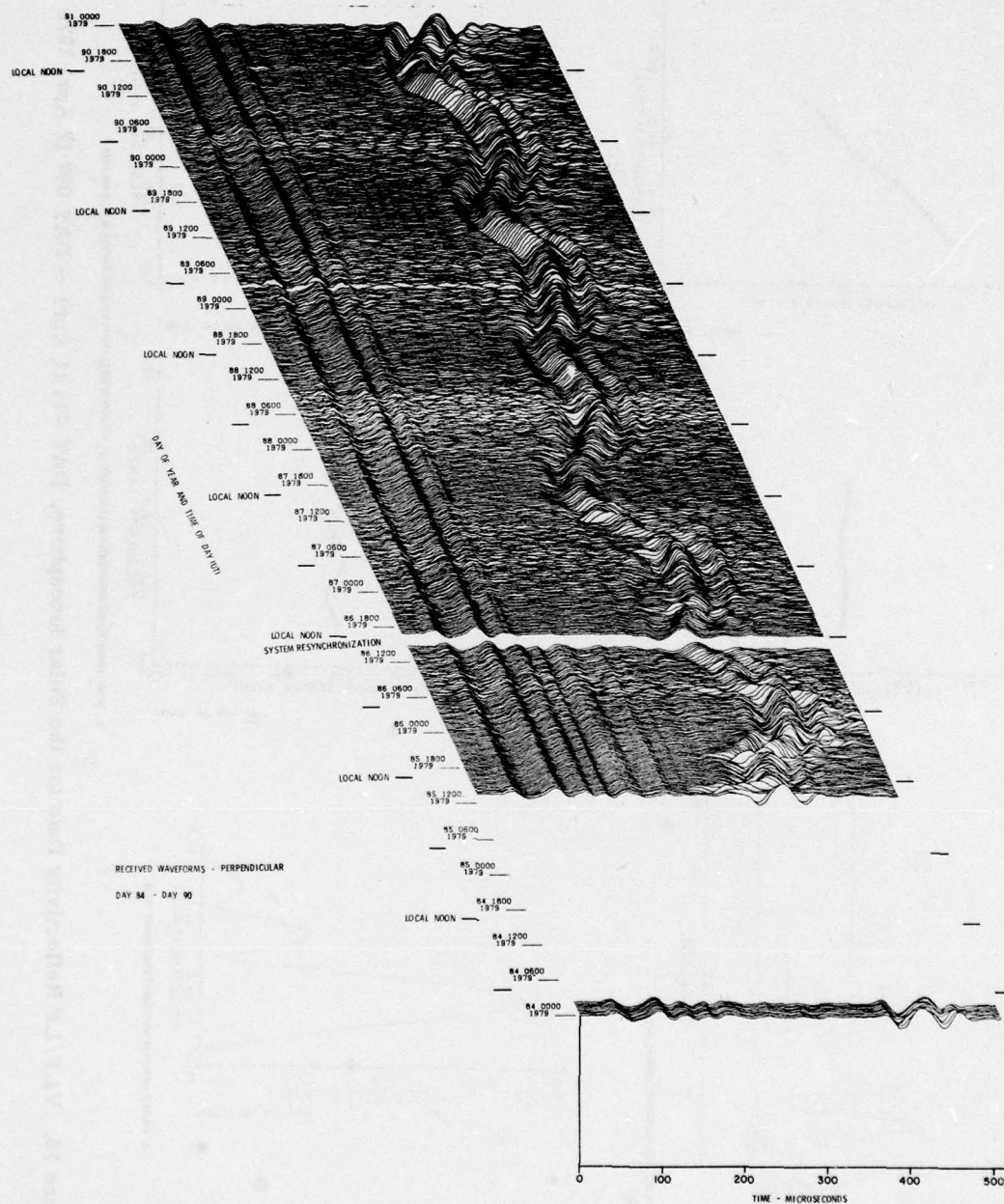


Figure 15. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 084 (25 Mar) - DAY 090 (31 Mar) 1979 (Cont)
Part S. \perp Waveform Display

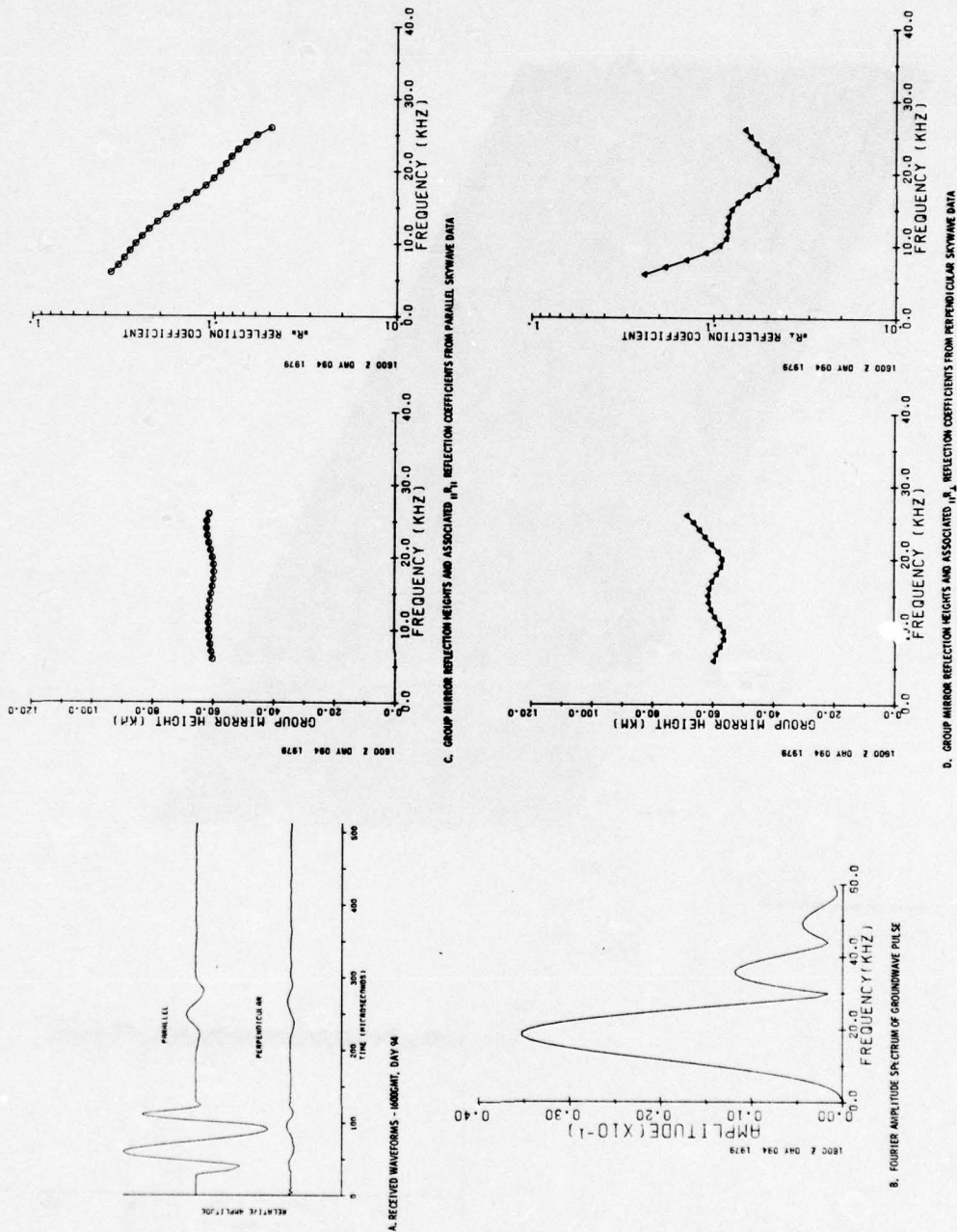


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 091 (1 Apr) - DAY 097 (7 Apr) 1979

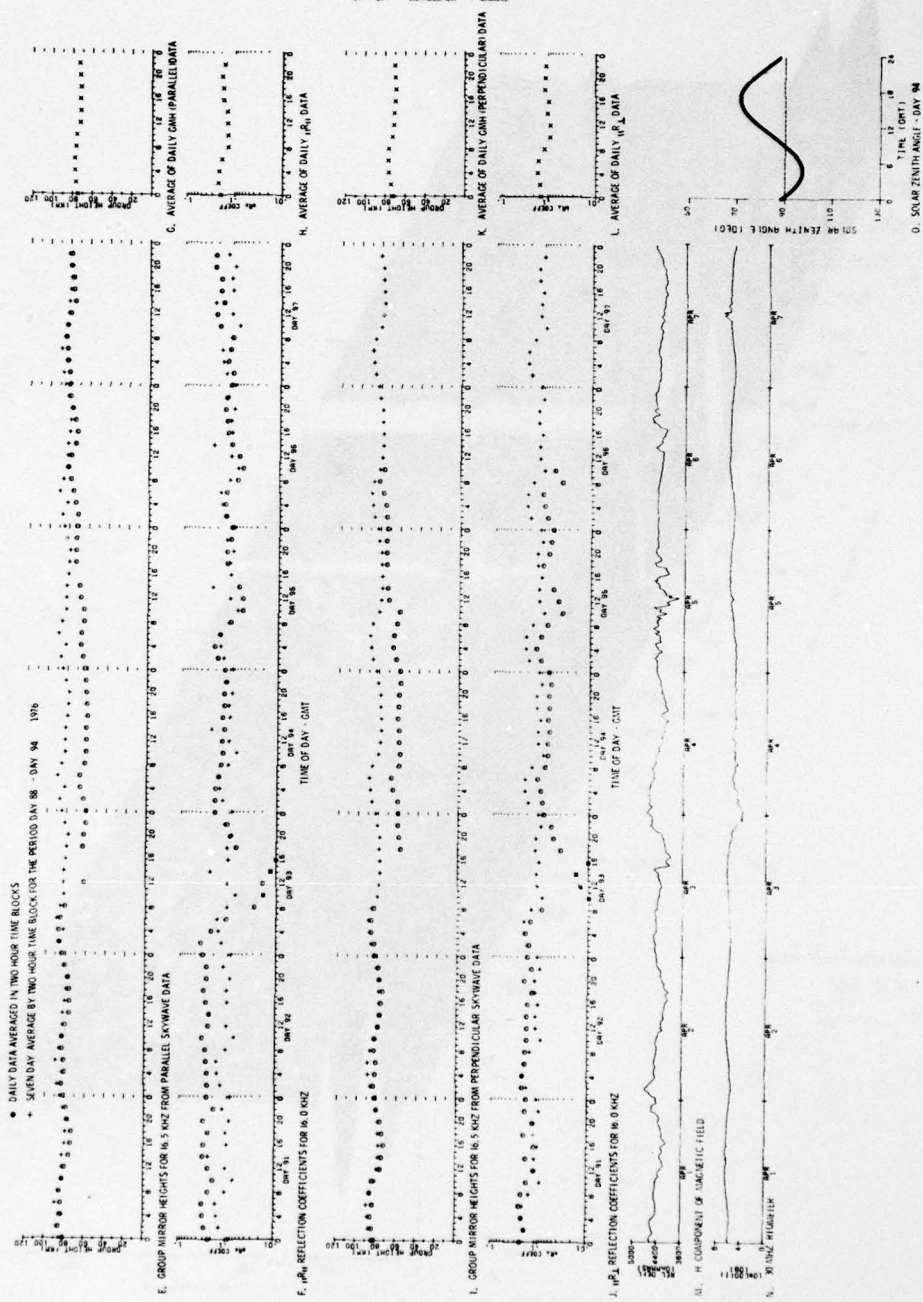


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 091 (1 Apr) - DAY 097 (7 Apr) 1979 (Cont)

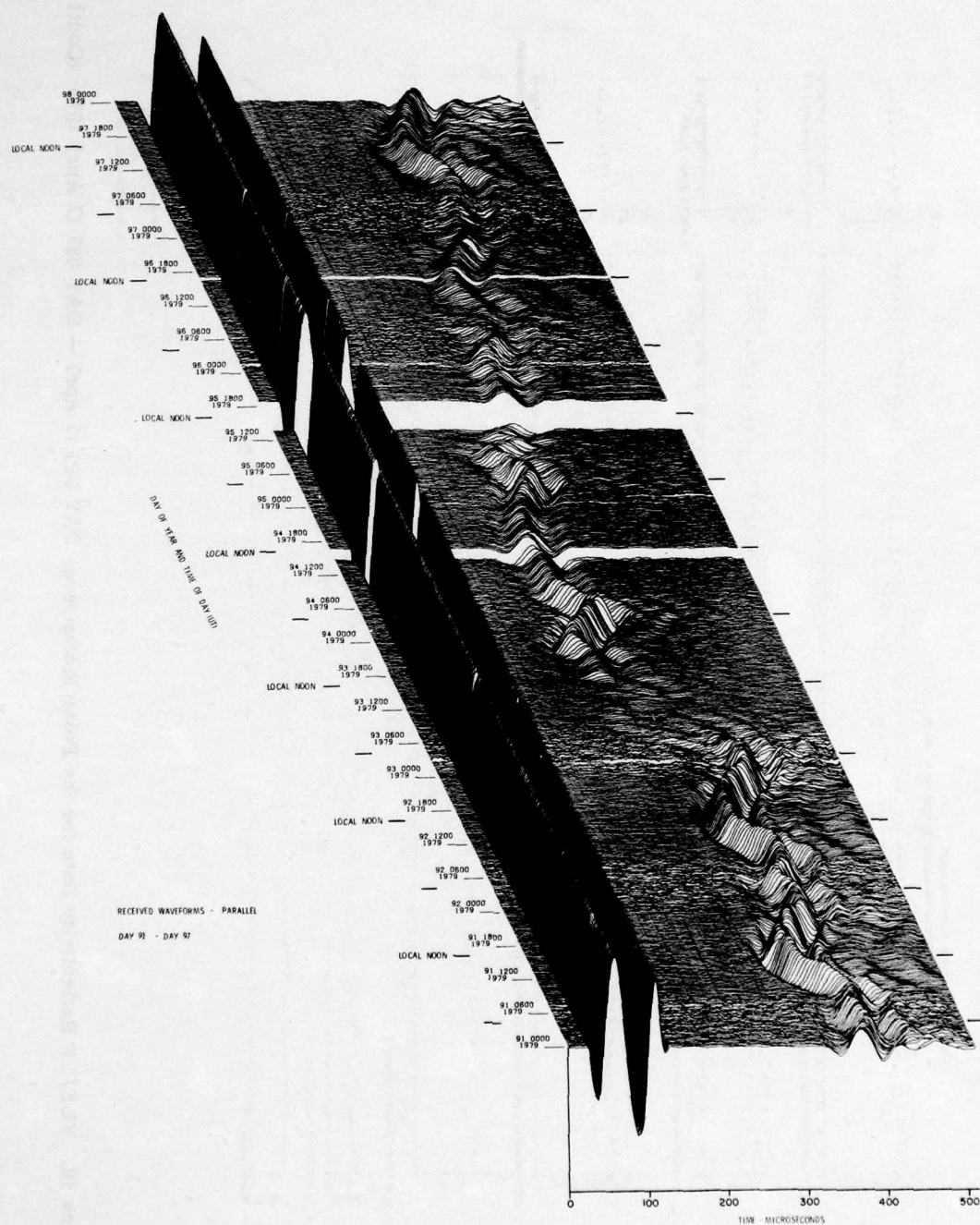


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 091 (1 Apr) - DAY 097 (7 Apr) 1979 (Cont)
 Part R. II Waveform Display

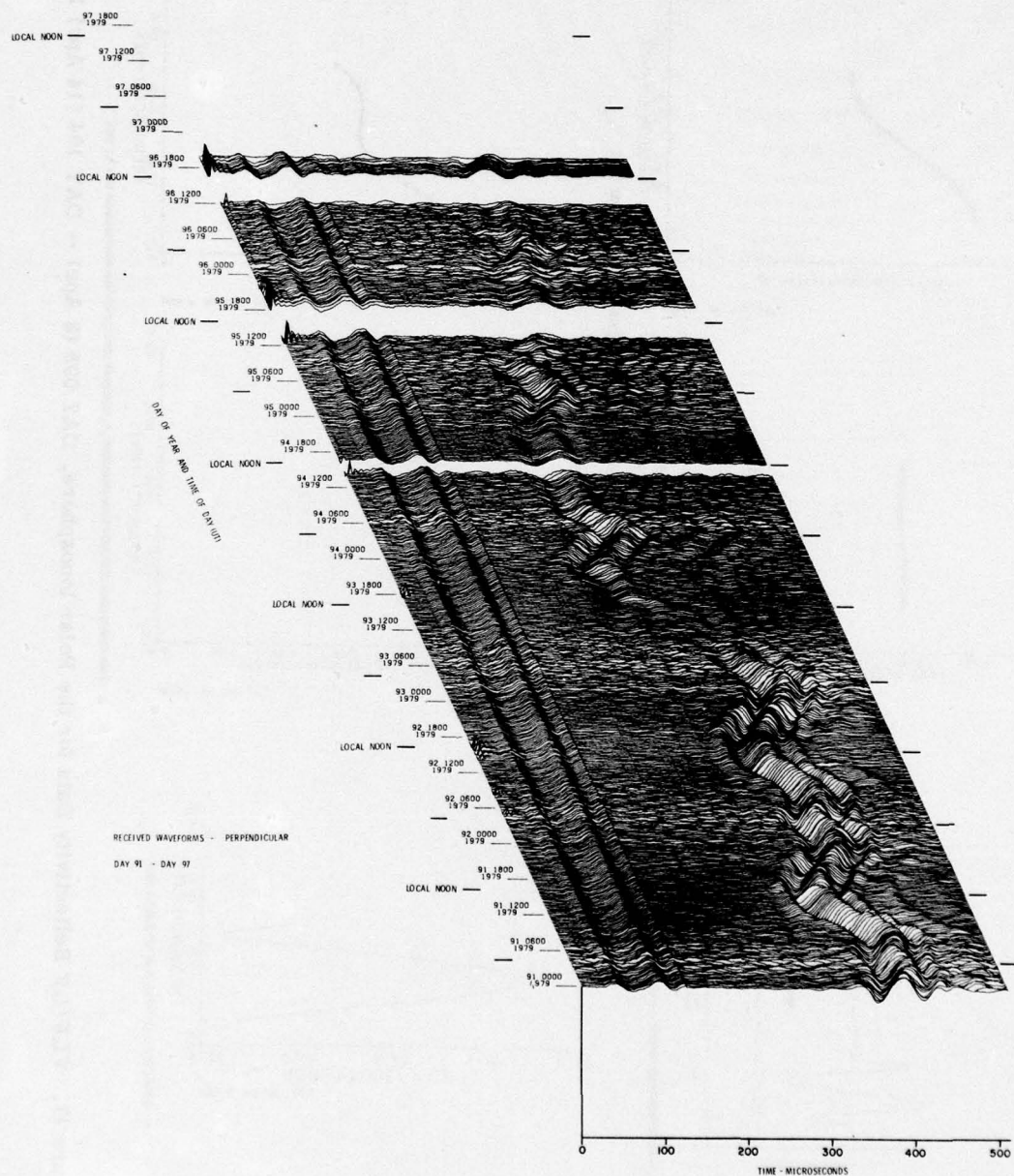


Figure 16. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 091 (1 Apr) - DAY 097 (7 Apr) 1979 (Cont)
Part S. \perp Waveform Display

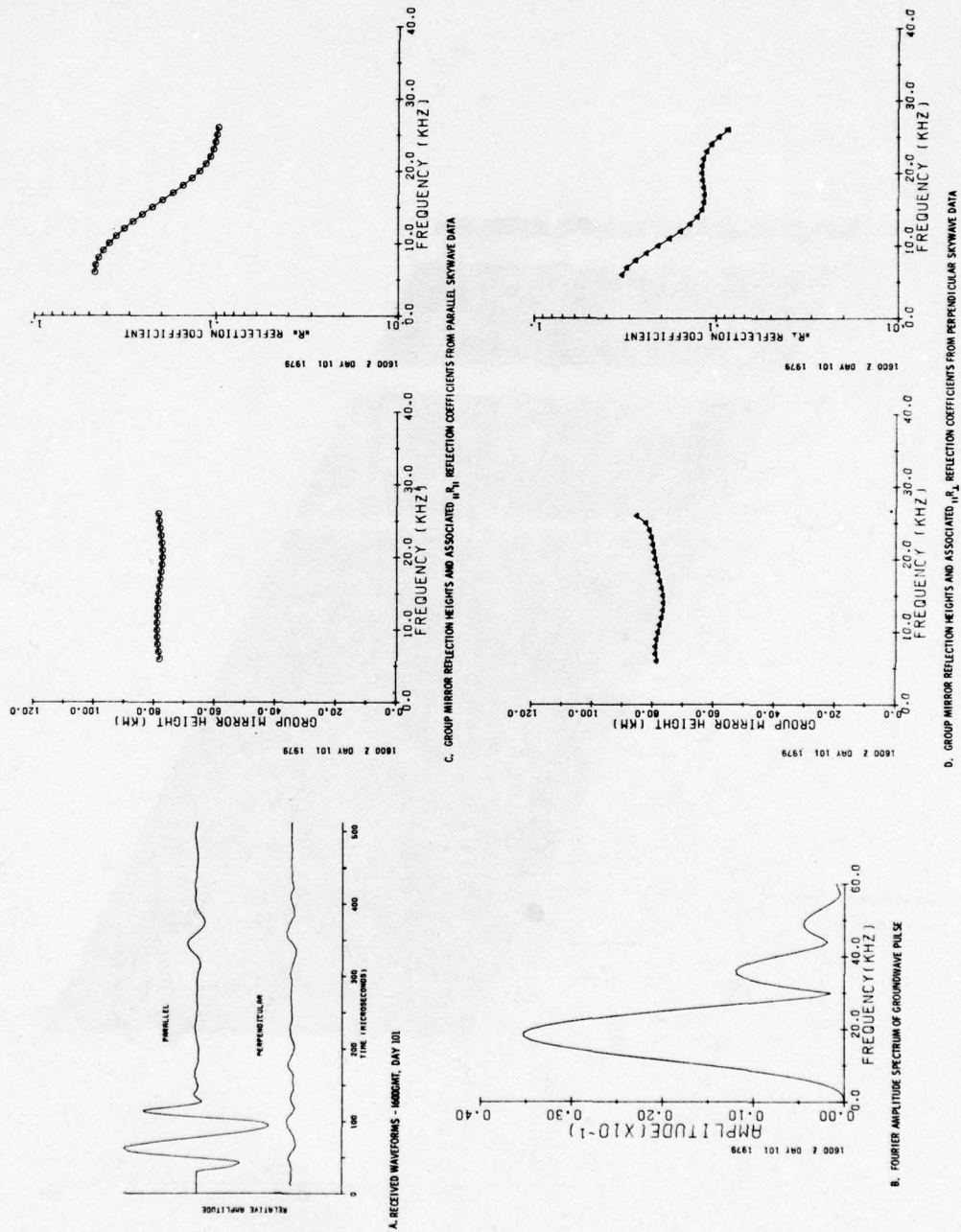


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 098 (8 Apr) - DAY 104 (14 Apr) 1979

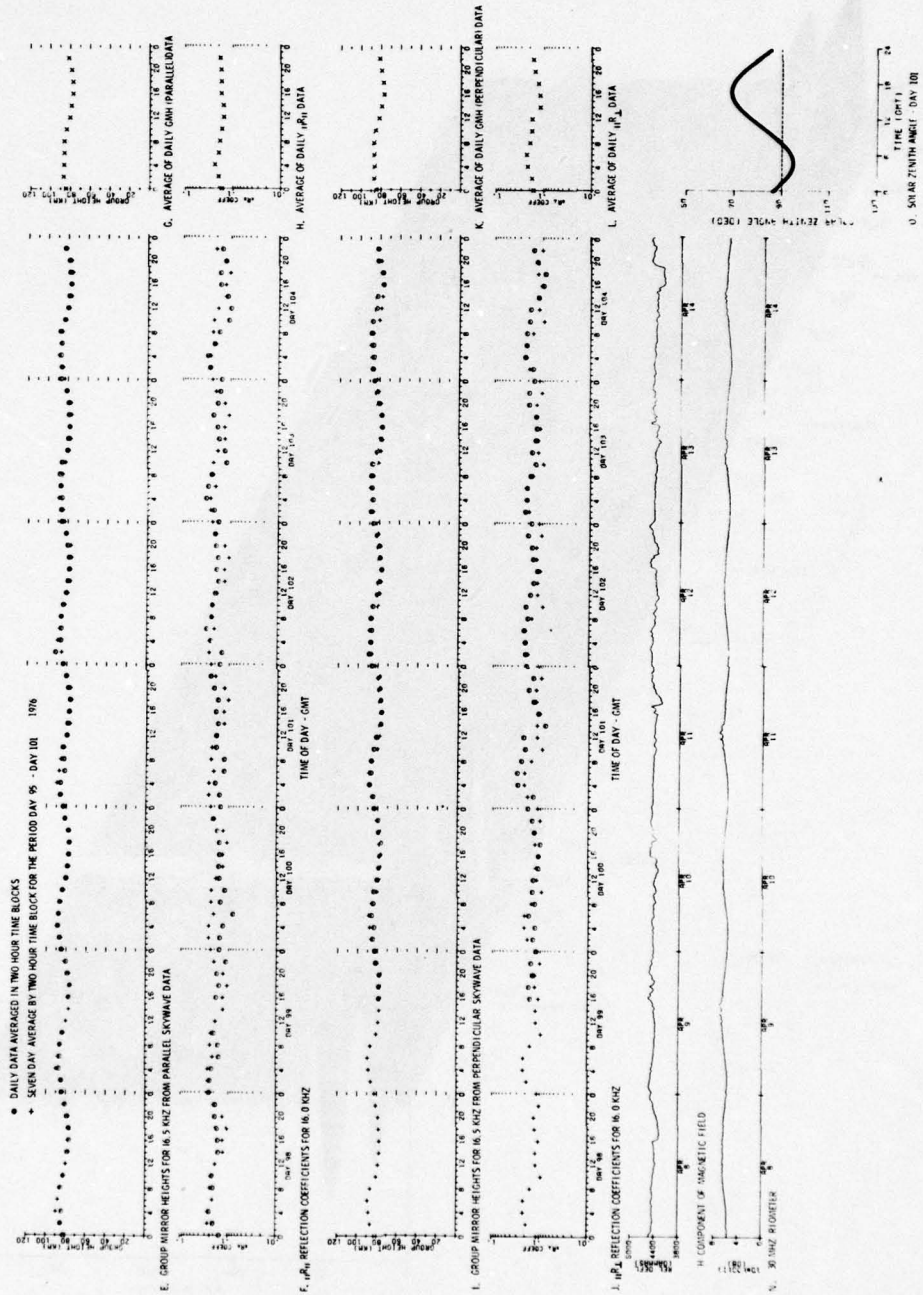


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 098 (8 Apr) - DAY 104 (14 Apr) 1979 (Cont)

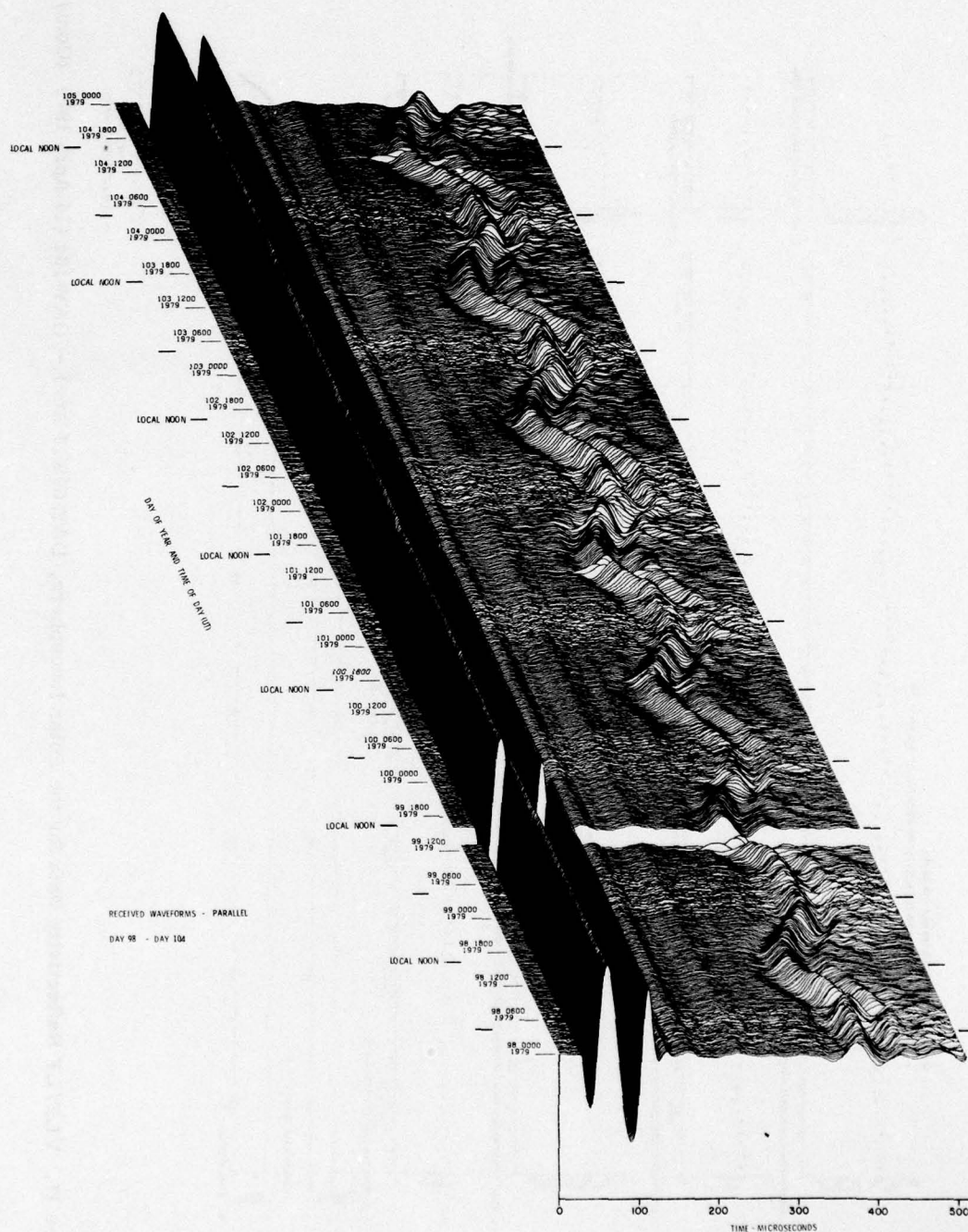


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 098 (8 Apr) - DAY 104 (14 Apr) 1979 (Cont)
 Part R. II Waveform Display

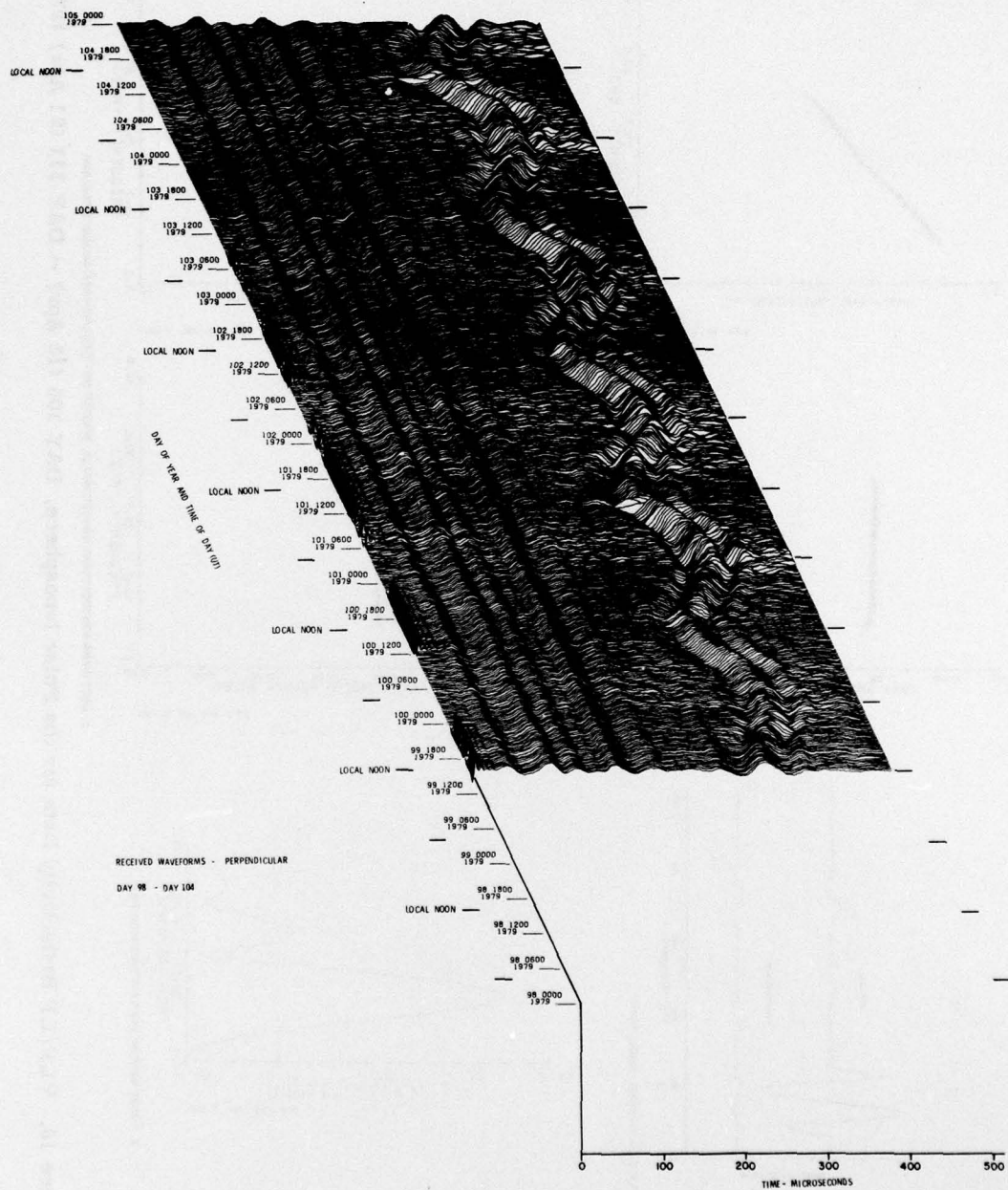


Figure 17. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 098 (8 Apr) - DAY 104 (14 Apr) 1979 (Cont)
Part S. \perp Waveform Display

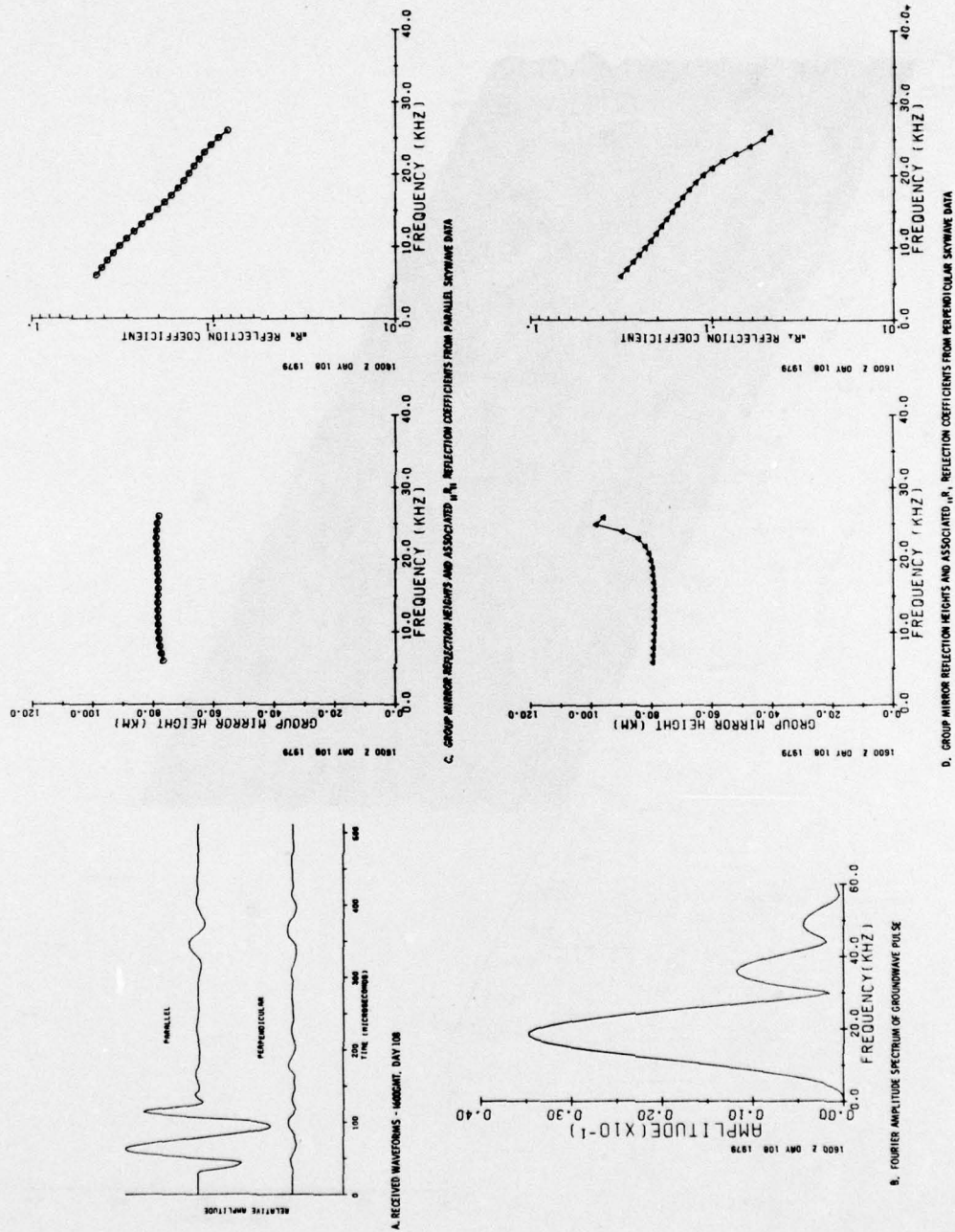


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 105 (15 Apr) - DAY 111 (21 Apr) 1979

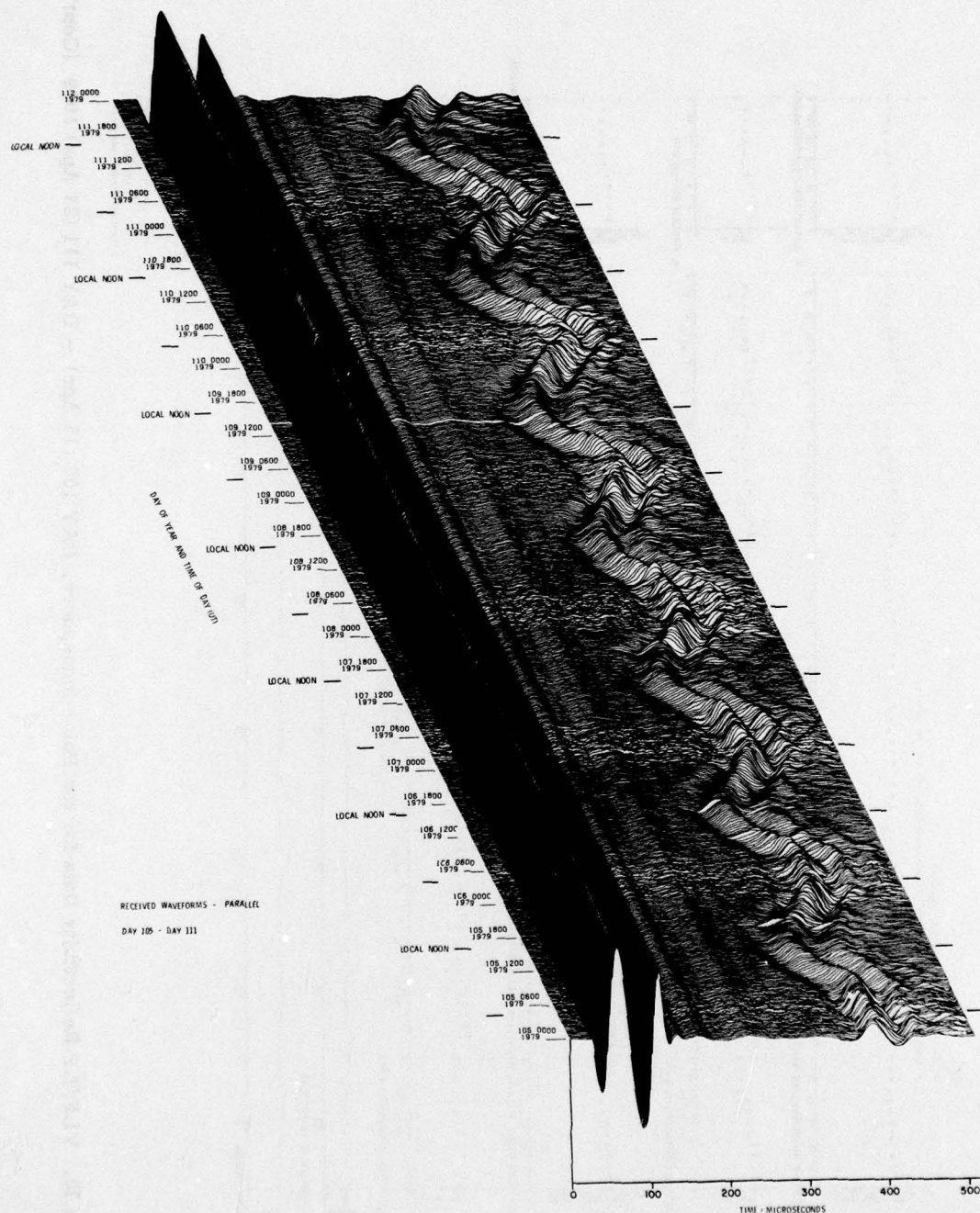


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 105 (15 Apr) - DAY 111 (21 Apr) 1979 (Cont)
 Part R. II Waveform Display

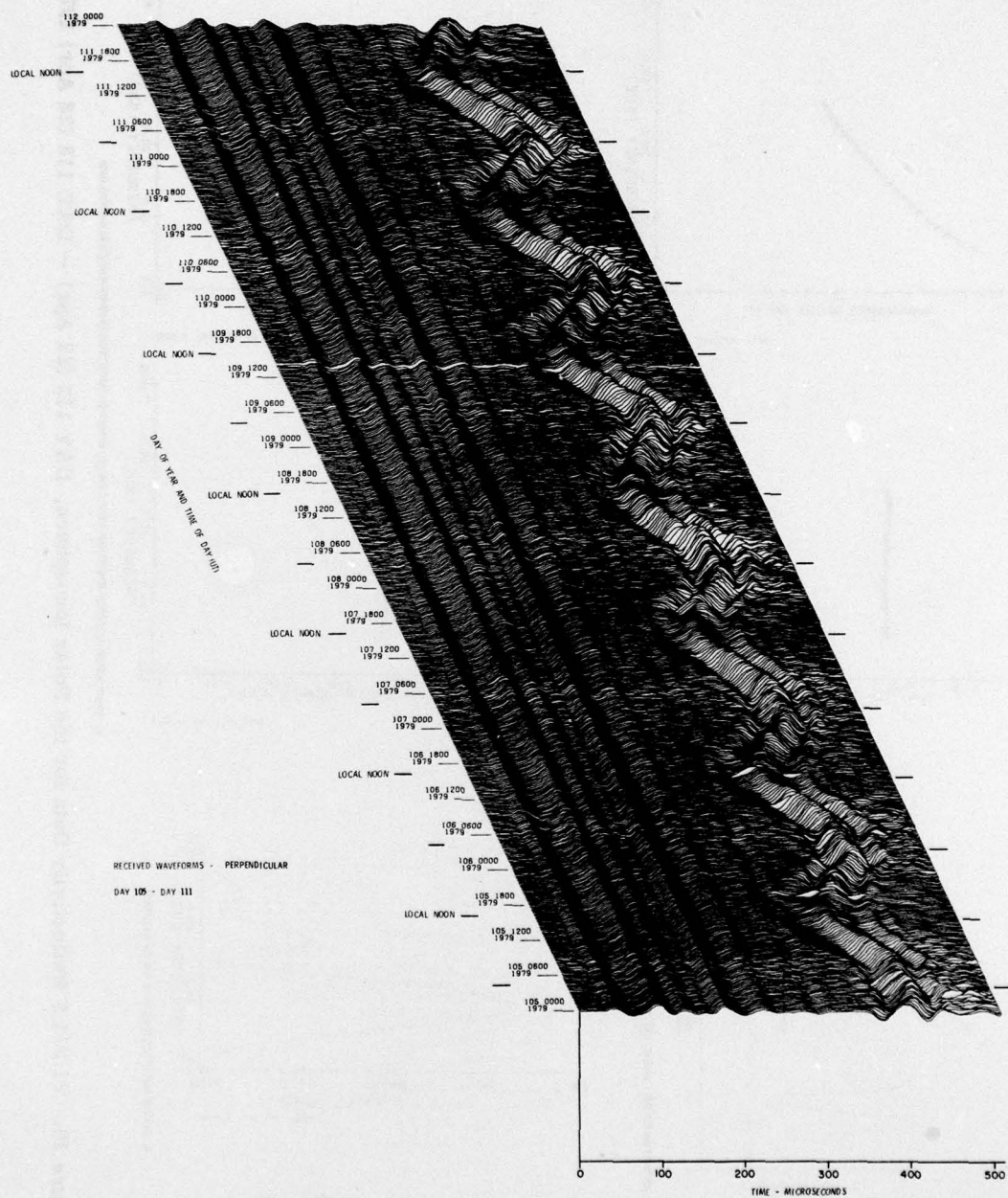


Figure 18. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 105 (15 Apr) - DAY 111 (21 Apr) 1979 (Cont)
 Part S. \perp Waveform Display

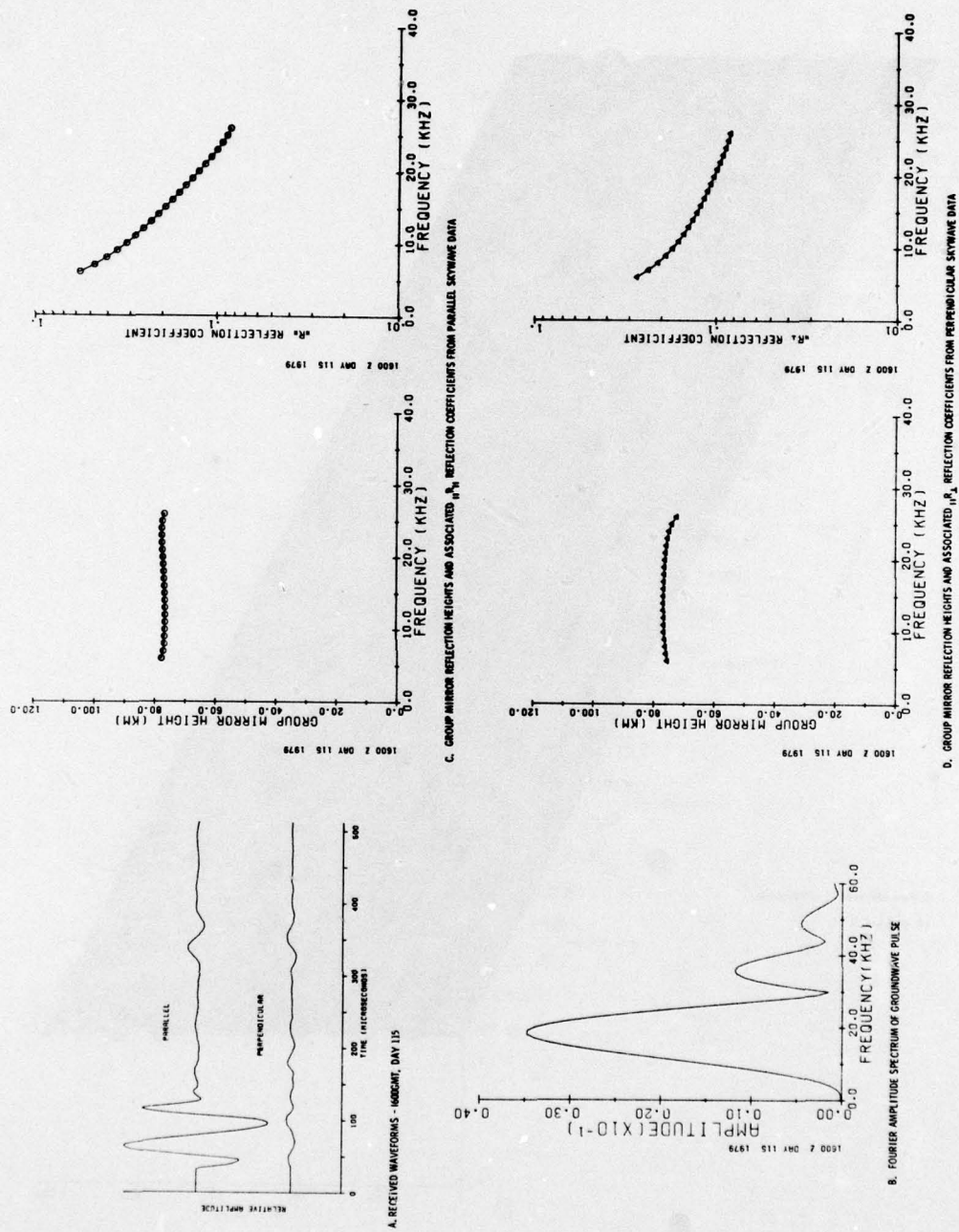


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 112 (22 Apr) - DAY 118 (28 Apr) 1979

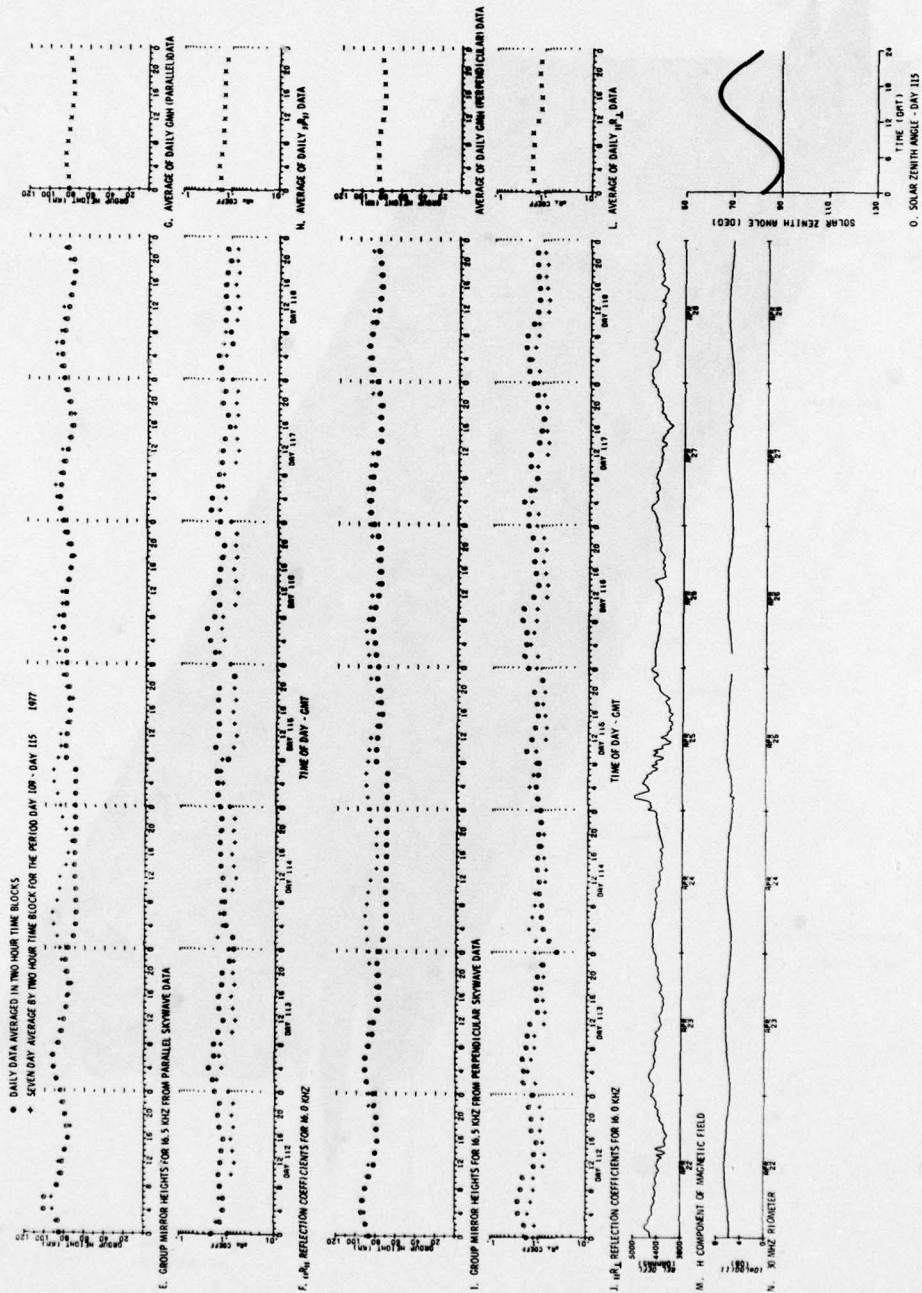


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 112 (22 Apr) - DAY 118 (28 Apr) 1979 (Cont)

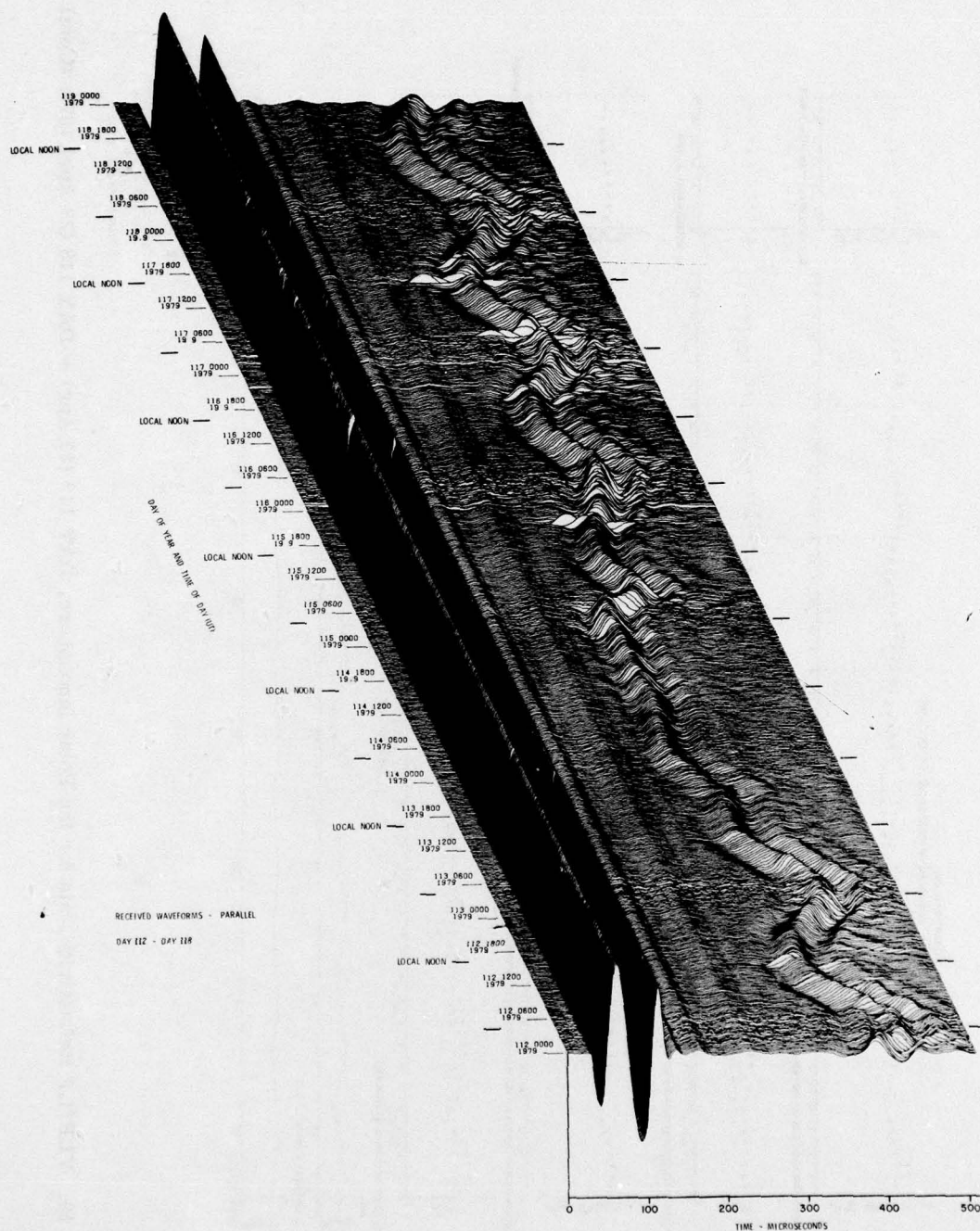


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 112 (22 Apr) - DAY 118 (28 Apr) 1979 (Cont)
Part R. II Waveform Display

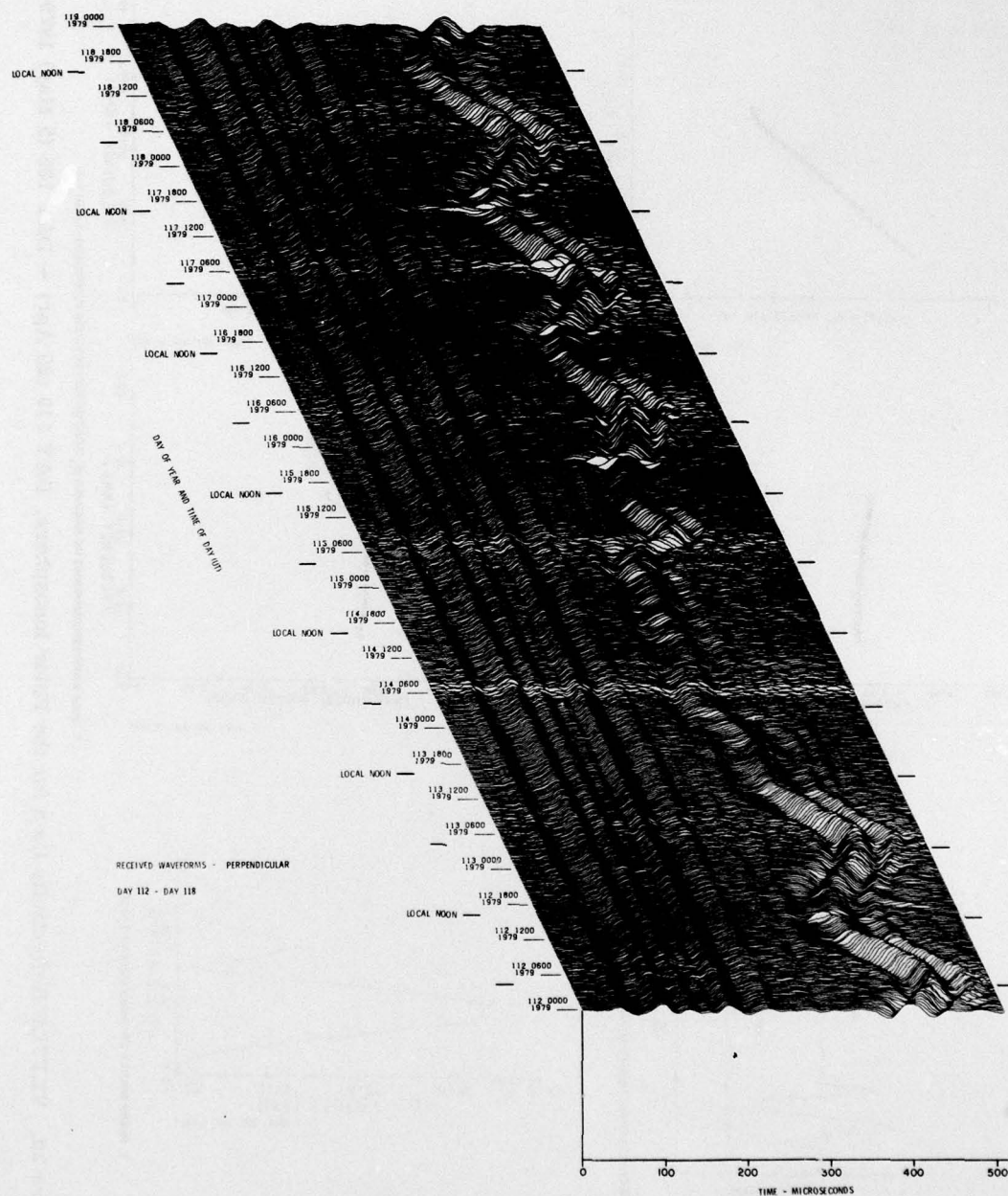


Figure 19. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 112 (22 Apr) - DAY 118 (28 Apr) 1979 (Cont)
Part S. \perp Waveform Display

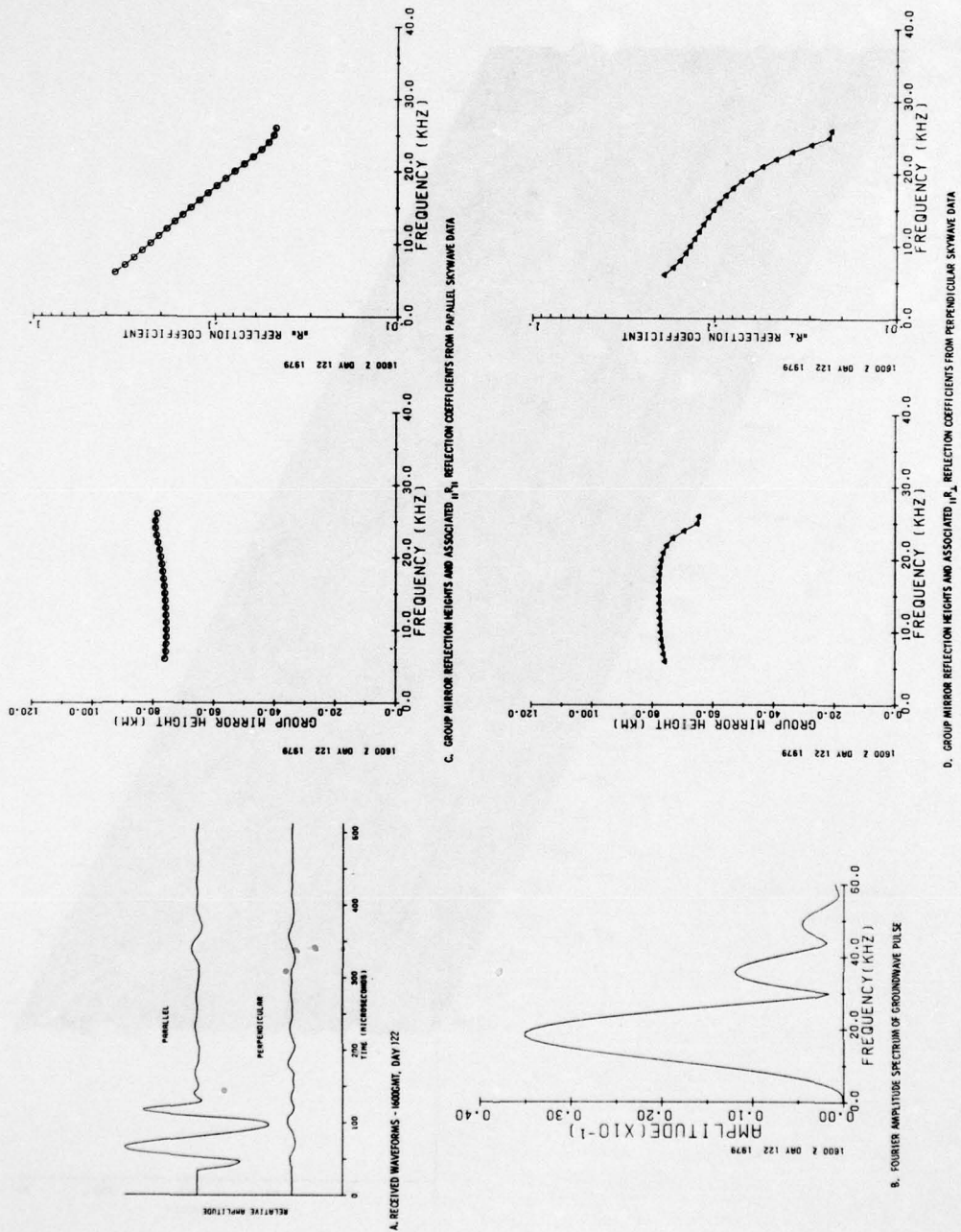


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 119 (29 Apr) - DAY 125 (5 May) 1979

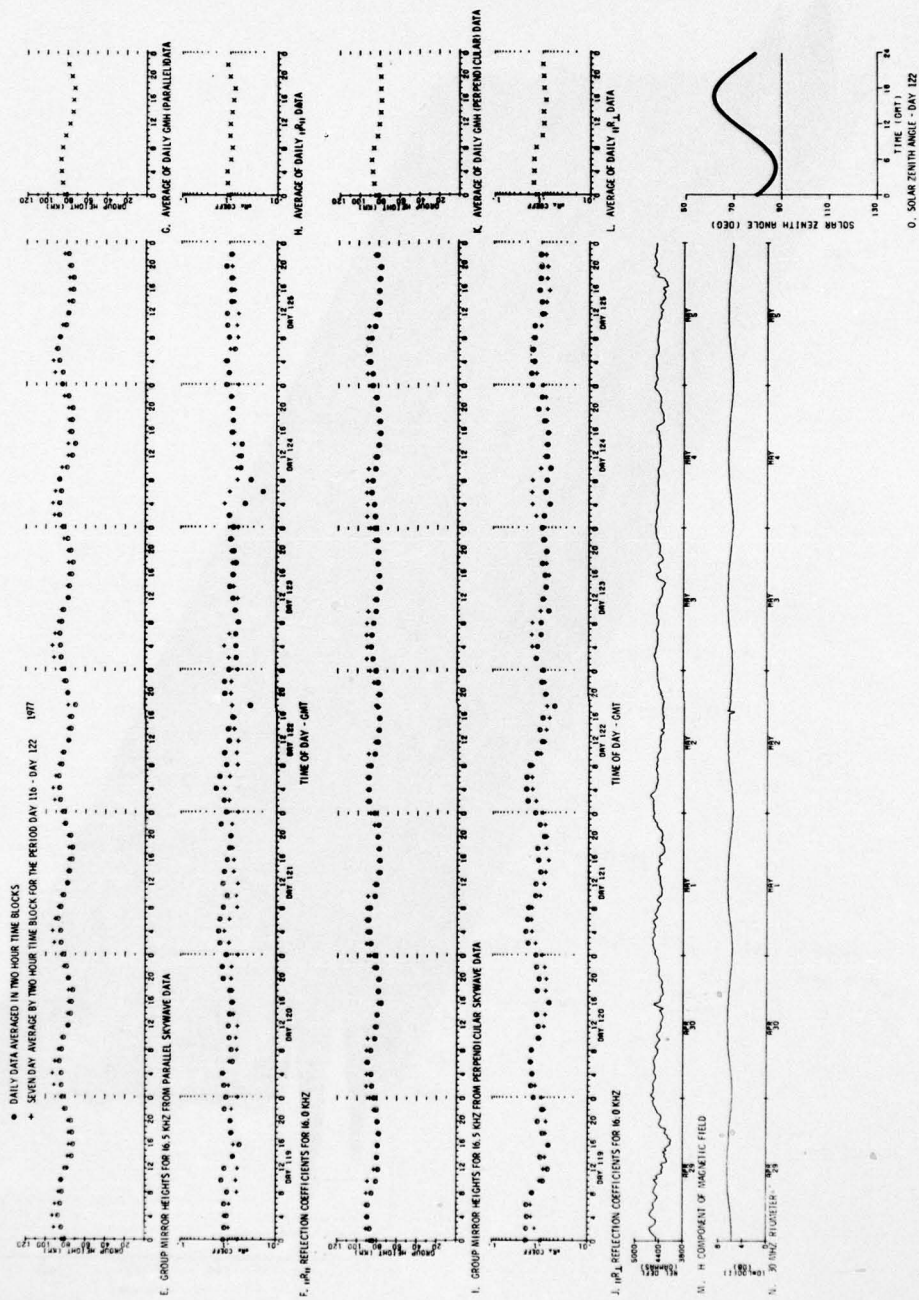


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere, DAY 119 (29 Apr) - DAY 125 (5 May) 1979 (Cont)

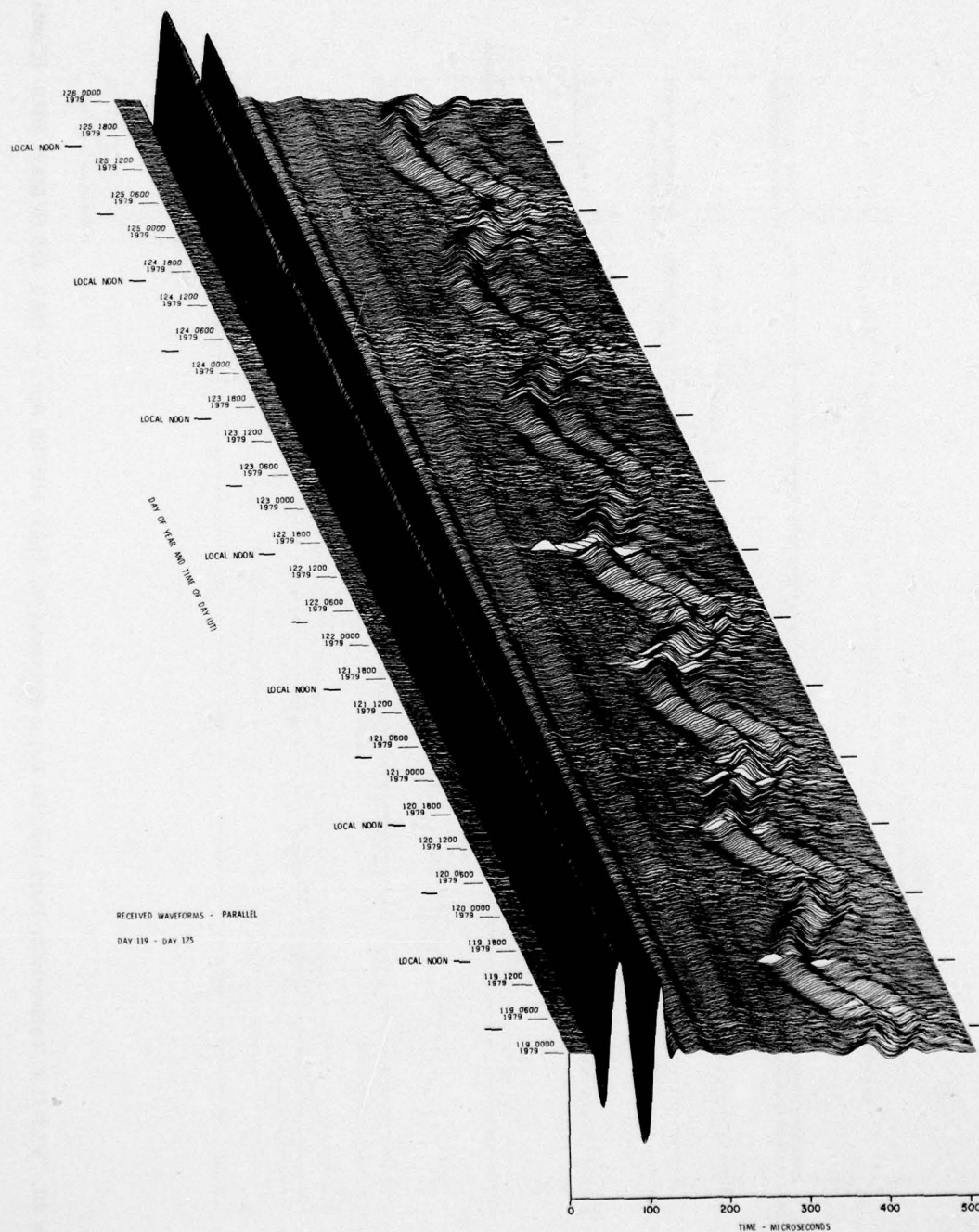


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere,
 DAY 119 (29 Apr) - DAY 125 (5 May) 1979 (Cont)
 Part R. II Waveform Display

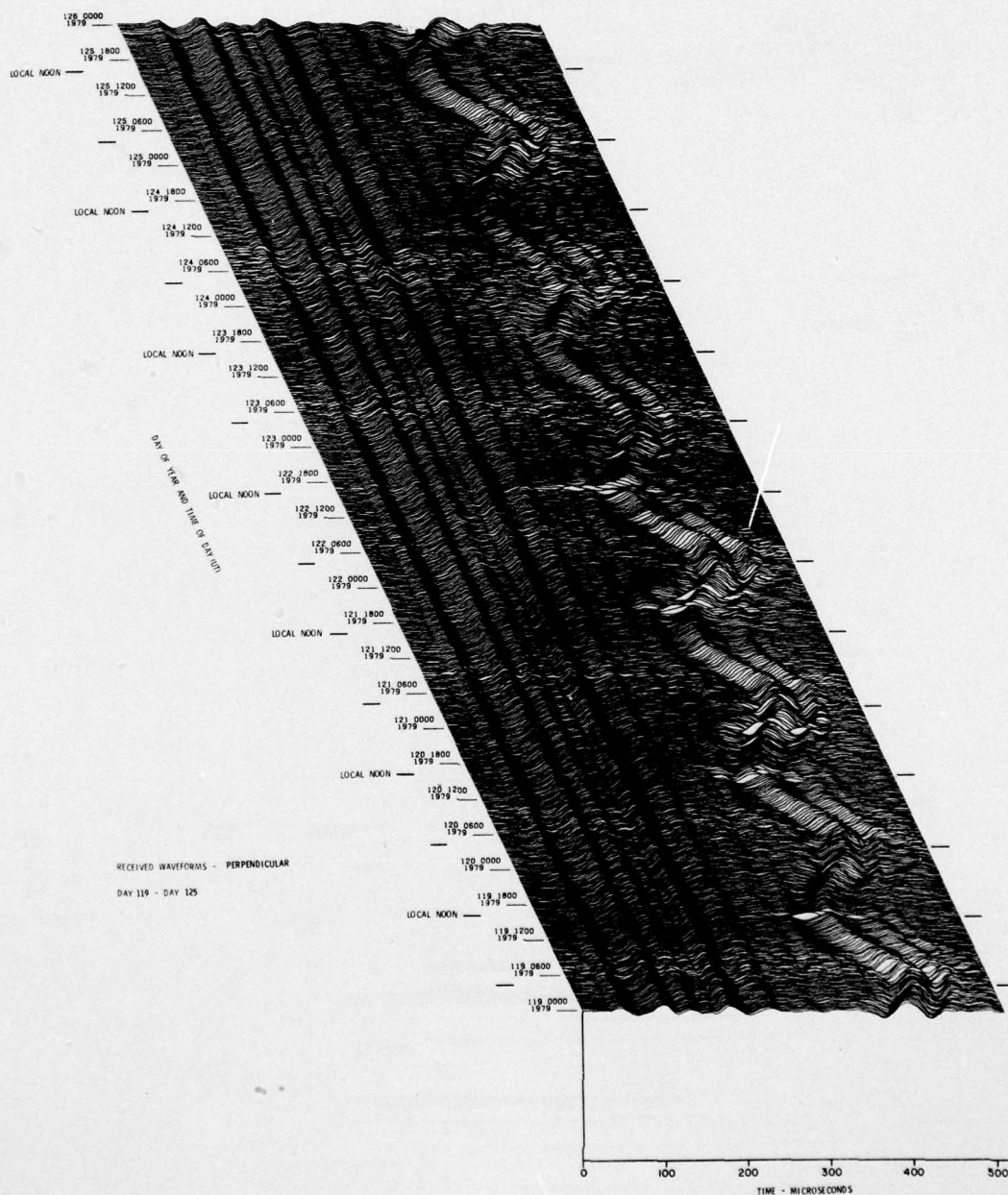


Figure 20. VLF/LF Reflectivity Data for the Polar Ionosphere,
DAY 119 (29 Apr) - DAY 125 (5 May) 1979 (Cont)
Part S. \perp Waveform Display

A decorative rectangular border with a repeating scroll-like pattern surrounds the central text.

MISSION of Rome Air Development Center

RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C³) activities, and in the C³ areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.